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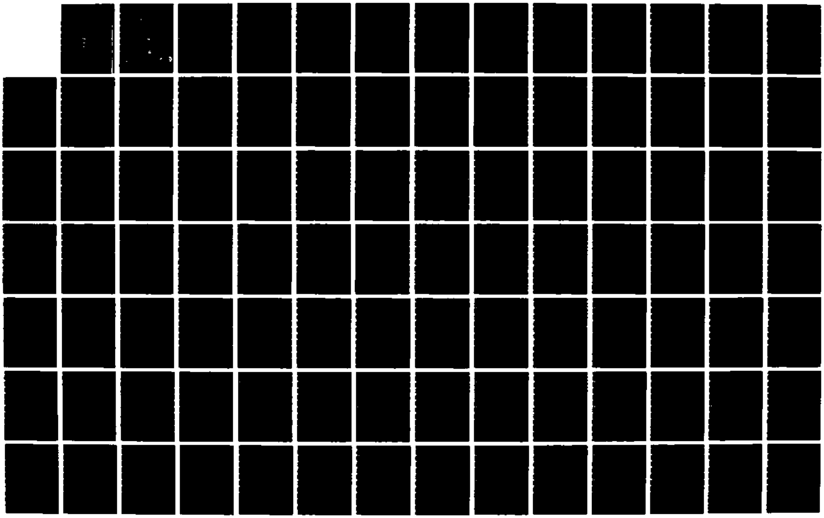

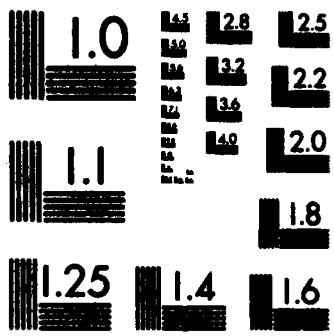
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ENGAGE II - User's Manual

by
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This user's manual describes ENGAGE II, a deterministic simulation of an Air Interceptor vectored toward a target, detecting a target, maneuvering to attain a missile launch position, launching missiles at the target and assessing their damage, and finally maneuvering into position to fire guns at the target. The model contains a 3 degree-of-freedom flight model for the AI, target, and missiles, and models both AI radar and a seeker

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Passive Track Adjunct for detection. It emphasizes the effects of aircraft maneuverability, radar detection and tacking, and radar missile detection when operating against targets with jamming capabilities and low radar cross section.

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1 INTRODUCTION

The ENGAGE II computer model was developed for the Aeronautical Systems Division of USAF/AFSC to enable them to assess the ability of modern interceptor aircraft armed with guided missiles and guns to attack maneuvering targets. The model is a major extension of the FIPDC and ENGAGE models that General Research has been developing since 1977.

Program ENGAGE II simulates the process of an airborne interceptor (AI) receiving vectoring toward the intended target, attempting to detect the target, maneuvering to attain a missile launch position, launching missiles at the target, and finally reaching a position to fire guns at the target. Program ENGAGE II treats each of these phases in some detail, emphasizing the aspect dependent nature of the target's detectability, the effects of jamming and ground clutter on the AI radar, and the maneuverability of the AI and missiles. The model includes a three degree-of-freedom flight model for the interceptor, target and missiles. The program considers the dynamic geometry and missile fly-out characteristics to calculate proper lead angles for missile flight. Active and semi-active radar missiles and passive (IR) missiles are modeled. The interceptor flight model includes the capability to break away and reattack from the stern, using rear-hemisphere missiles and guns.

Detection is achieved by either the fighter radar or a passive search set. The program is capable of modeling multi-mode radar and accounts for the effects of ground clutter, aspect-dependent radar cross section of the target, and electronic countermeasures (ECM). The passive search set is sensitive to range and target aspect, but is assumed to be unaffected by clutter or ECM.

The purpose of this User's Manual is to provide non-programming users of ENGAGE II with the information necessary to use the model effectively. Because no other documentation is being prepared for this model, mathematical treatments of radar detection, jamming, missile launch conditions, and AI, missile and target flight are included in the appendices. Section 2 of this manual describes the processes that are modeled and the implementation of the modeling. Section 3 describes the input and Section 4 includes a sample problem. The various types of output of the program are described in Section 5.

2 THE INTERCEPT PROCESS

This section describes the physical system of the intercept process and its implementation in the computer model ENGAGE II. Section 2.1 provides an introduction, Sec 2.2 provides an overview of the simulation model, Sec 2.3 lists and briefly describes the major events modeled in the intercept process, and Sec 2.4 describes the basic program flow. Section 2.5 mentions some of the uses and limitations of the model. Throughout this section, when references are made to program inputs, the input name is included in capital letters within parentheses.

2.1 INTRODUCTION

Program ENGAGE II is a deterministic simulation of a fighter aircraft being vectored toward a target, detecting it, maneuvering to attain a missile launch position, launching missiles at the target, and finally reaching a position to fire guns at the target. ENGAGE II is a three-degree-of-freedom simulation of aircraft and missile flight, and can thus provide a graphic picture of the interception process. No random numbers are used in the simulation. Instead, probabilities are calculated and integrated numerically, and the program will output the probability of the fighter's detecting a target and converting to a firing position—the well-known probability PDC—and the probability that the missiles launched will destroy the target, the probability of kill, PK.

2.2 INTERCEPT MODEL OVERVIEW

The model is designed to allow the user to generate an average PDC for a scenario by automatically running a series of engagements at different geometries, and then averaging the result. The user defines the number of Heading Crossing Angles (NHCA) and the number of Offsets (NOFF). An engagement is generated for each Heading Crossing Angle and Offset combination. The Heading Crossing Angles are input by the user.

The offsets may be input (IOFDIS = 2) by the user, or they may be generated by the program from a single nominal input distance (OFF(1)) for either a uniform distribution (IOFDIS = 0) or a normal distribution (IOFDIS = 1).

2.3 ENGAGE II ENGAGEMENT EVENTS

The ENGAGE II simulation models the engagement of an airborne interceptor (AI) and a moving target as a series of events. Once the engagement begins, the AI attempts to detect, then to track the target with the AI radar, to maneuver into a position to launch missiles, and to reach a gun-firing position. The model is a time-based simulation, which steps forward in time seeking to satisfy the criteria for the next possible event or events. Whenever an event occurs, it is recorded by the routine HISTRY; the Event History Output lists all of the events of an engagement, their times, and the AI and target locations at the time of the event. The following is a list of these major events in the simulation. The event name is underlined in the list. The routines referred to in this list are shown in the hierarchy chart of Fig. 2.1.

- <u>INITIATION</u> -- INITIATION OF THE ENGAGEMENT
  This event initiates the AI and target states at the beginning of the engagement. The engagement time clock begins at 0 seconds. This event is generated in routine PINIT.

- <u>PTA DETECT</u> -- AI PASSIVE TRACK ADJUNCT TARGET
  This event occurs when the Passive Track Adjunct system onboard the AI detects the target before the AI radar does. This event is generated in routine DETECT.

- <u>DETECTION</u> -- AI RADAR DETECTION OF TARGET
  This event occurs when the AI radar first detects the target. This event is generated in routine DETECT.

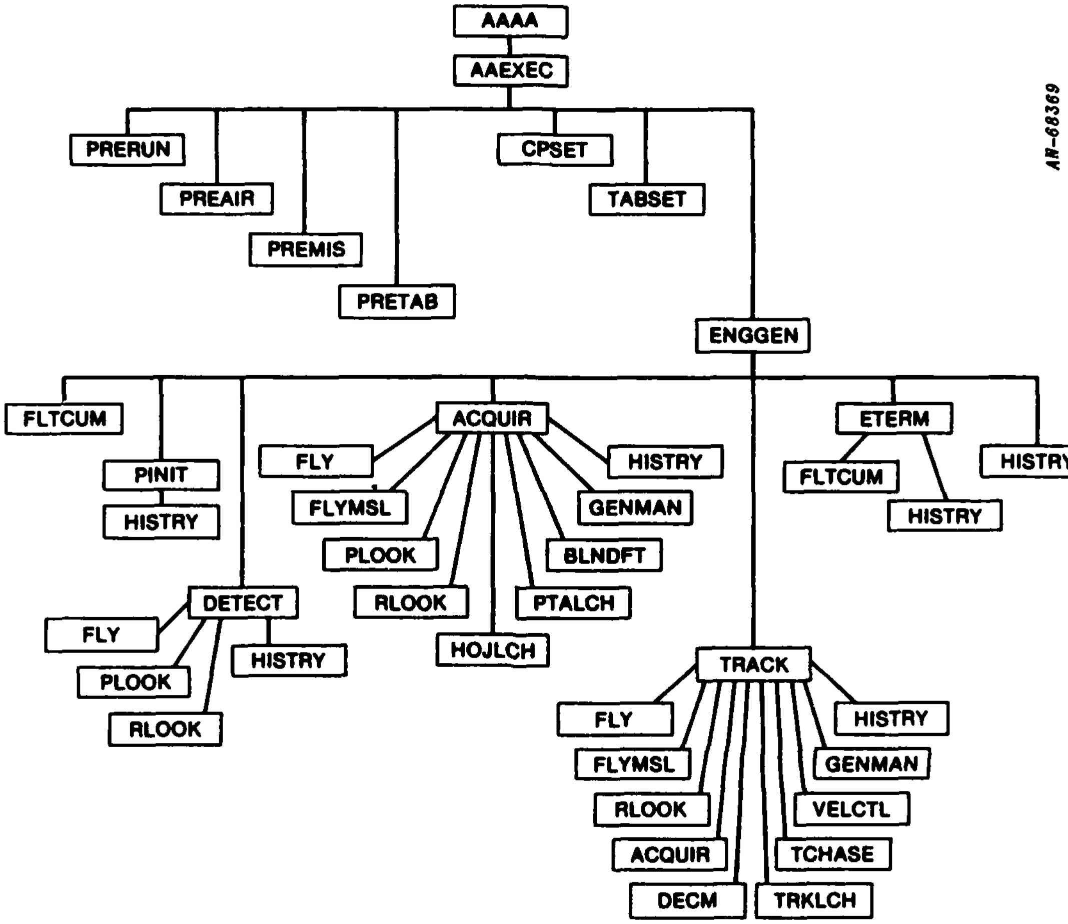


Figure 2.1. ENGAGE II Basic Routine Hierarchy Chart

- <u>TRACK</u> — AI BEGINS TRACK OF TARGET

  This event occurs when the AI radar is able to lock-on to the target and track it. This event is generated in routine ACQUIR.

- <u>AAM LAUNCH</u> -- AI LAUNCHES MISSILE

  This event occurs when the AI launches a missile. This event is generated in routines HOJLCH, PTALCH, and TRKLCH.

- AAM IMPACT -- MISSILE REACHES CLOSEST APPROACH TO TARGET
  This event occurs when an in-flight missile makes its closest approach to the target. This is the point when the range rate between the missile and the target first becomes zero or positive. This event is generated in routine FLYM.

- AAM ABORT -- MISSILE FLIGHT ABORTS
  This event occurs when an in-flight missile fails in flight, for one of three possible reasons: it hit the ground; the flight time exceeded the maximum allowed guided flight time (TDMAX); or the blind flight time exceeded the maximum allowed blind flight time (TDMIN). This event is generated in routine FLYM.

- LOST TRACK -- AI RADAR LOSES TRACK OF TARGET
  This event occurs when the target is invisible to the AI radar for a period longer than the tracking filter can automatically update without new data (TCOAST). This event is generated in routine TRACK.

- GUN POSITION -- AI REACHES SUCCESSFUL GUN POSITION
  This event occurs when the AI maneuvers into position to fire its guns at the target. This position is an area defined by the user with ranges (RCREAR and RLREAR) and the angle (AREAR) off the tail of the target. This event is generated in routine TRACK.

- END TRACK -- ENGAGEMENT ENDS AFTER SUCCESSFUL AI RADAR TRACK
  This event occurs at the end of an engagement in which the AI radar has been able to successfully track the target. This event is generated in routine TRACK.

- NO DETECT -- ENGAGEMENT ENDS WITH NO DETECTION
  This event occurs at the end of an engagement in which the AI has not detected the target with either the AI radar or the Passive Track Adjunct. This event is generated in routine DETECT.

- ONLY PTA -- ENGAGEMENT ENDS WITH PASSIVE TRACK ADJUNCT TARGET DETECTION, BUT NO AI RADAR DETECTION
  This event occurs at the end of an engagement in which the AI Passive Track Adjunct has successfully detected the target, but the AI radar has not. This event is generated in routine DETECT.

- DET NO TRK -- ENGAGEMENT ENDS WITH AI RADAR DETECTION, BUT NO AI RADAR TRACK
  This event occurs at the end of an engagement in which the AI radar has detected the target, but has not been able to establish a track on it. This event is generated in routine ACQUIR.

- TERMINATION -- ENGAGEMENT SUMMARY
  This event occurs after the end of the engagement. The model assures that all missiles launched during the engagement either have reached closest approach or have aborted, then calculates the Probability of Kill, PK, for the engagement. This event is generated in routine ETERM.

2.4 THE PHYSICAL PROCESS AND THE MODEL

2.4.1 Introduction

The process of target interception has the following phases:

- GCI Vectoring

  In this phase, the AI is under the control of a vectoring agency and is on an approximately collision, non-maneuvering course with the target. This phase ends after the AI detects the target and declares its independence from the vectoring agency.

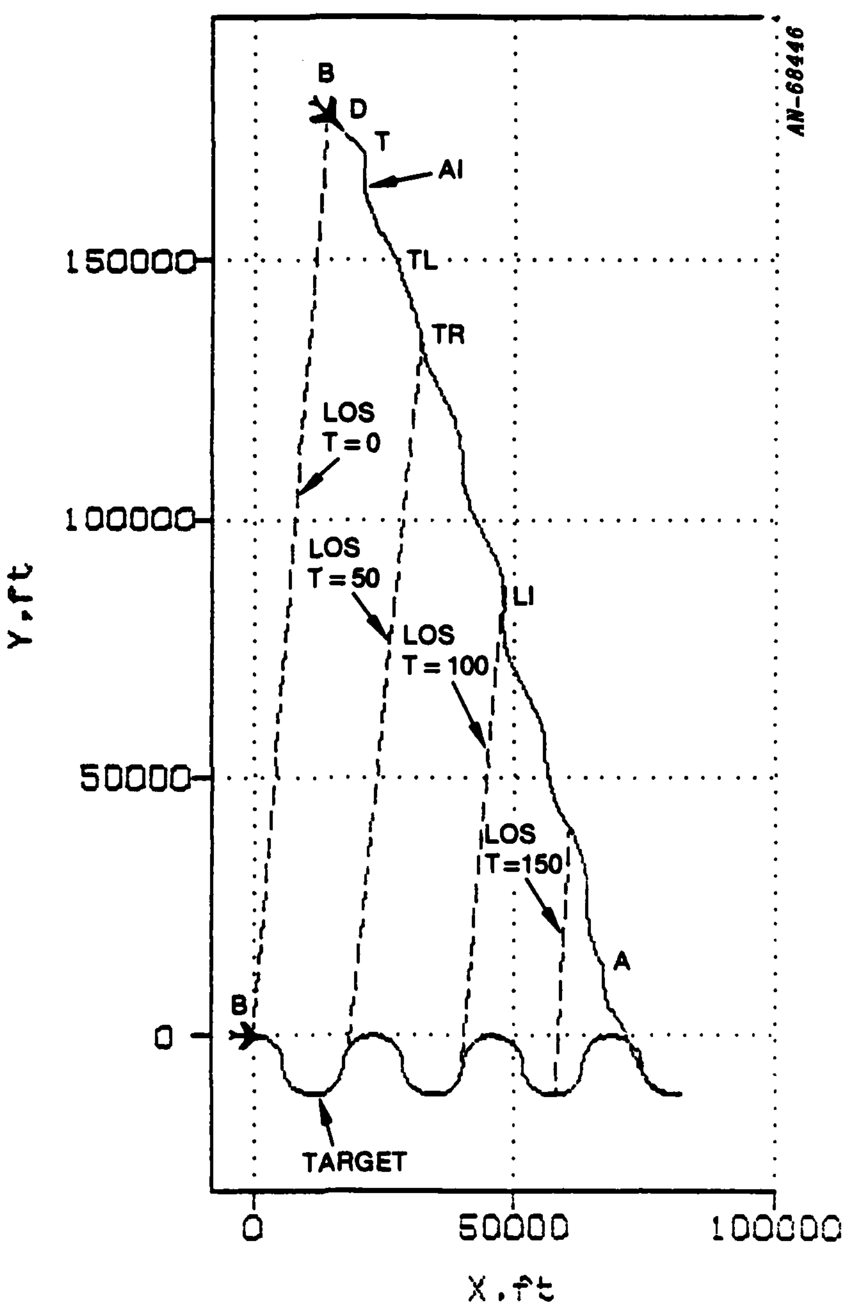
- Conversion

  In this phase, the AI begins to follow the target with its own onboard receiving devices, obtains steering information, and eventually launches air-to-air missiles (AAMs). This phase ends at the first AAM launch.

- Attack

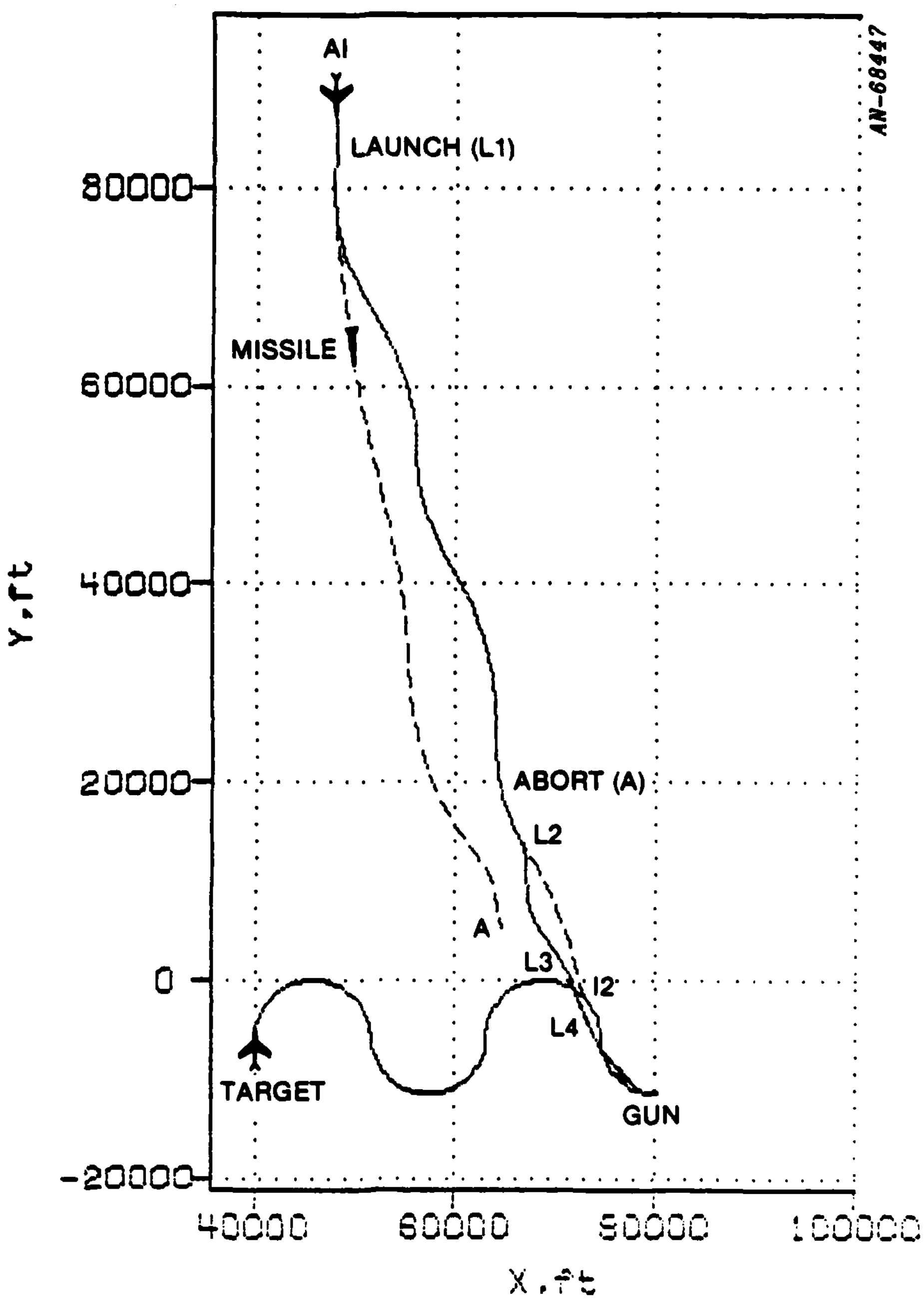
  In this phase, the AI continues to maneuver to maintain the proper course for further AAM launches and support for in-flight missiles, if they employ semi-active radar seekers. This phase includes the assessment of AAM launches and the launch of subsequent missiles. The AI will attempt to convert to a stern attack to launch rear-aspect IR missiles, if the original attack is from the front and the IR missiles have no forward-hemisphere capability. If the AI is carrying guns, the AI will attempt to maneuver to a stern gun-firing position. The phase ends when all missiles have been launched and a gun-firing position has been achieved; when the target is lost; or when the AI has exceeded its maximum engagement flight time.

Figure 2.2 illustrates the process of target interception. The entire engagement is illustrated in the first plot. The initial vectoring conditions are defined by a 45 degree Heading Crossing Angle and a 5000 foot offset, assuming the target flight is straight with no velocity change. The target, however, is maneuvering in a sinusoidal



(a) Entire Engagement

Figure 2.2. Target Interception



(b) Attack Phase

Figure 2.2. (Cont.)

pattern at the bottom of the plot. The dashed lines represent lines of sight every 50 seconds. The engagement begins at B, and detection occurs at point D. Track begins at point T, then is lost briefly at point TL when Signal-to-Interference drops below threshold, and is regained at TR. The wavering path of the AI is due to the changing aim point based on the straight-line projection of the target flight path. Eventually, all missiles on board are launched and successful gun position is reached. The flight then terminates. The second plot illustrates the missile launches (dashed lines), and begins at the first radar missile launch point L1. This launch is based on a straight-line projection of the target flight, which would have indicated a nearly head-on collision in the middle of the plot. Instead, the target maneuvers kept the target beyond the maximum guided flight time allowed the radar missile, and it aborted at point A. The second radar missile launch, point L2, immediately after the assessment of the first missile's abort, is successful at point I2. Both IR missiles are then launched at points L3 and L4, and impact before the AI reaches gun position, point GUN.

The remainder of this section will discuss the target interception process in more detail, as it is implemented in the simulation.

2.4.2 <u>GCI Vectoring</u>

The model-user provides the information to establish the beginning of the engagement, which simulates the GCI vectoring instructions for the AI. These user inputs also establish the errors in the GCI vectoring instructions. These inputs include the Heading Crossing Angle (HCA) between the headings of the AI and the target, the offset (OFF) of the AI from a collision course, the lag (DLAG) of the the target from a collision course, and the initial distance between the AI and the target at the beginning of the engagement (RO and RPI, the initial ranges for HCA = 0 degrees and HCA = 180 degrees, respectively.) The range at the beginning of the engagement, assuming no offset, is interpolated from RO and RPI for the HCA. Then if there is any offset, the AI is "backed up" to insure the initial distance is at least as great as the interpolated range without offset. These user inputs and the initial locations of the target and the AI at the beginning of an engagement are illustrated in Figure 2.3. The coordinate system used in the simulation is chosen so that, at the beginning of the engagement, the target is at the origin (or offset from it by DLAG along the positive X-axis), and is traveling along the positive X-axis.

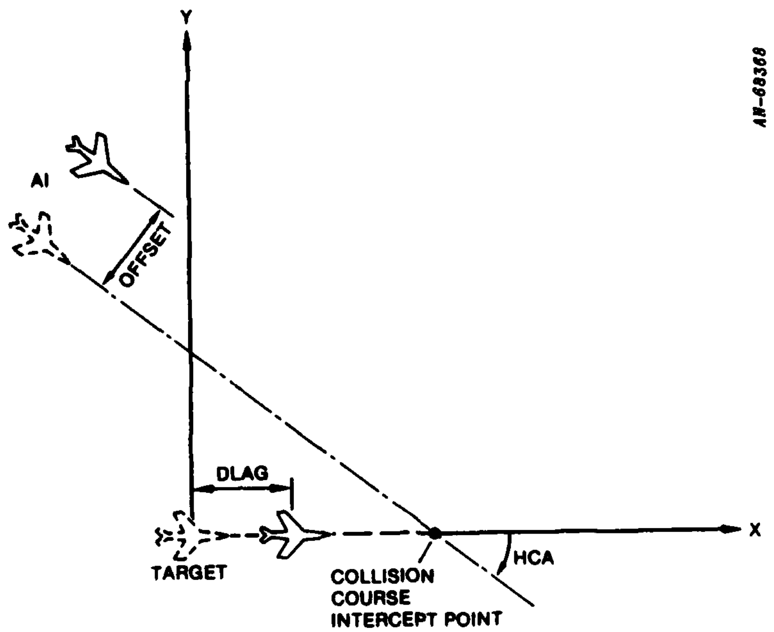


Figure 2.3. Initial Engagement Geometry

The AI, once given the initial GCI vectoring instructions, continues in a straight path until detection. The target may maneuver at any time, as the user defines in the target maneuver inputs. At the beginning of the engagement, all receiving equipment onboard is on, attempting to detect the target. The AI has 3 methods of detection: AI Radar detection; Passive Track Adjunct Detection; and Track-on-jam Detection. Each of these will be described in detail.

<u>AI Radar Detection</u>. The AI radar model in ENGAGE II computes the signal-to-interference ratio within the AI radar at each scan across the target and deduces a detection probability on each scan. These probabilities are accumulated to derive the cumulative detection probability. The interference includes mainlobe clutter residing outside the passband of the doppler filter containing the target, sidelobe clutter inside the passband, and the thermal noise inside the passband. Appendix A describes the meaning of these clutter categories. The dependence of clutter upon the doppler frequency of the target signal and the dependence of mainlobe clutter upon the beam depression angle are both accounted for. If the target has jamming capability, the signal-to-interference ratio also includes the noise jamming. This and other types of ECM included in the model are described in Appendix B.

The simulation accommodates radars of a pure waveform, or those with time-shared waveforms, which interleave low-PRF, medium-PRF, and high-PRF waveforms. These waveforms differ in the model in the effects of in-band and mainlobe clutter. Appendix A describes these differences. The model-user provides parameters for all those waveforms available on the AI radar, and the model determines the best (highest signal-to-interference ratio) waveform of those available to attempt detection.

Target detection requires that the AI radar antenna be scanning the air volume containing the target. The ENGAGE II simulation has a complete model of the antenna scanning process (Fig 2.4). The model-user inputs the antenna scan control settings. This requires the user to decide how much guidance to give the AI pilot concerning the probable radar contact range and target altitude. The ENGAGE II model provides the option of an antenna scan limited only by gimbal limits (GIMBAZ and GIMBEL), if the user wishes to avoid the question of providing guidance to the AI pilot. The input elevation scan control parameters (BARSEP, ELBARS, and ELCTR) are only used to determine the antenna scan time. Use of this option assumes the pilot has been given adequate information to scan the correct elevation angle for the target.

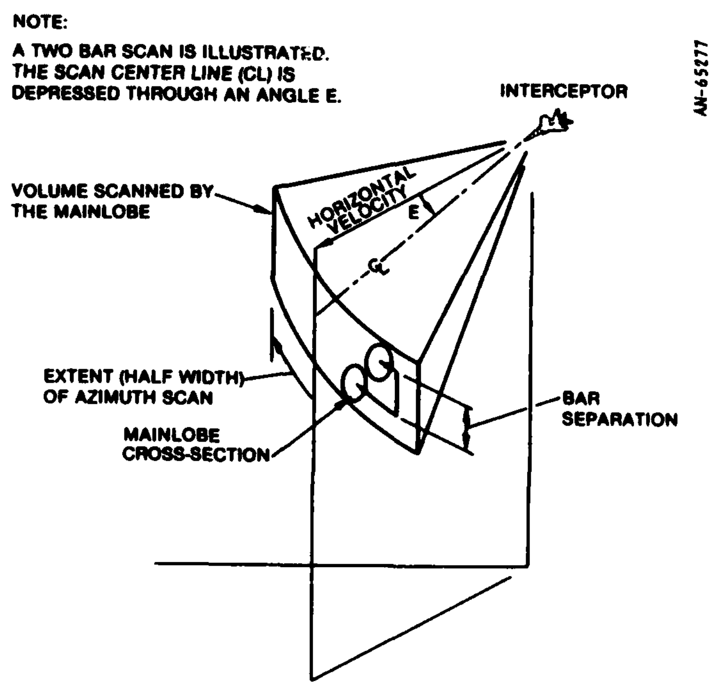


Figure 2.4. Antenna Scanning Process

Target detection is a random event in the real world. It can occur at any range corresponding to some single-scan detection probability. The user may choose either of two ways to define the radar detection event as occurring. The first (IDETYP = 1) is based on successive detections by single-scans, in which the single-scan probability of detection exceeds an input threshold (DCRIT). The detection event occurs when at least 'k' blips (KBLIP) in the last 'm' scans (MSCAN) have appeared on the screen. For example, an automated detection scheme might require 3 out of the last 8 scans to exceed a single-scan detection probability of 0.5 (KBLIP = 3, MSCAN = 8, and DCRIT = 0.5). The second method (IDETYP = 2) defines the detection event as occurring when the the cumulative probability of detection meets or exceeds the input probability threshold (DCRIT). The cumulative probability is given by:

$$\text{PDCUM} = 1 - \prod_{i=1}^{N} [(1 - \text{SSPD}(i)]$$

where SSPD(i) is the single scan probability of detection for scan i, and N is the number of radar scans.

The radar cross section of the target is input as a table (RCSTABLE) of average values at a number of equally-spaced aspect and elevation angles. In addition, several other target parameters are aspect-dependent in the simulation, such as the jammer ERP (ERPTABLE), the Passive Track Adjunct lock-on range (PTATABLE), the IR missile lock-on range (IRMSLRANGE), and an optional added miss distance for each of the missile types (IRMISSERR and RADMISSERR). The simulation uses two-dimensional interpolation in all of these tables.

Passive Track Adjunct Detection. The AI may have a Passive Track Adjunct (PTA) onboard to aid in target detection. This capability is modeled in two modes, Radar Clue Mode (PTATYP = 1) and Autonomous Mode (PTATYP = 2). Detection is based on a target-aspect-dependent lock-on range, input by the user (Table PTATABLE). The model requires the target to be within user-input scan limits (PAZSCN and PELSCN) for successful detection. If the PTA is in Radar Clue Mode and successfully detects the target, the PTA provides the AI radar with a better prediction of the target location, and the AI radar can narrow its own scan limits. This is modeled by reducing the AI radar scan period to a refined AI radar scan period (TSTA2R) that the user inputs. If the PTA is in Autonomous Mode and successfully detects the target, then after a delay (TSTARE) to provide time to determine the target range, the AI pilot has enough information (range and angle) to begin the conversion phase; to steer toward the target, and to attempt to launch missiles. The model assumes the range rate is unknown, however, so no lead predictions are made. See Appendices C and D for descriptions of maneuvers and aimpoints.

Home-on-Jam Detection. If the target is actively jamming, and the AI radar has the capability to track a jamming signal, then detection can occur when the jamming signal is above the track-on-jam threshold (TTOJ). The track-on-jam radar mode can give the pilot enough information (angle, but not range or range rate) to begin the conversion phase; to steer toward the target, and to attempt to launch missiles. Since the model assumes that only the target angle is known, the missile is aimed directly at the target.

Detection, then, can be accomplished by the AI radar in a clear environment, or by burnthrough in a jamming environment (providing target angle, range, and range rate); or by an onboard Passive Track Adjunct (providing target angle and range); or by the track-on-jam mode of the AI radar (providing target angle only). These are in descending order of preference because of the information provided, with AI radar detection being preferred. Once detection by any method occurs, the model will seek to improve the information to the AI pilot with a better form of detection, but will not continue to attempt detection with a less effective method. The model logic for the detection process is shown in Fig. 2.5.

The second type of jamming modeled in ENGAGE II can occur at this time. This is called Track Break jamming; and it is implemented by denying lock-on as long as the jammer-to-signal (J/S) ratio exceeds the jammer effectiveness threshold (TJEFF).

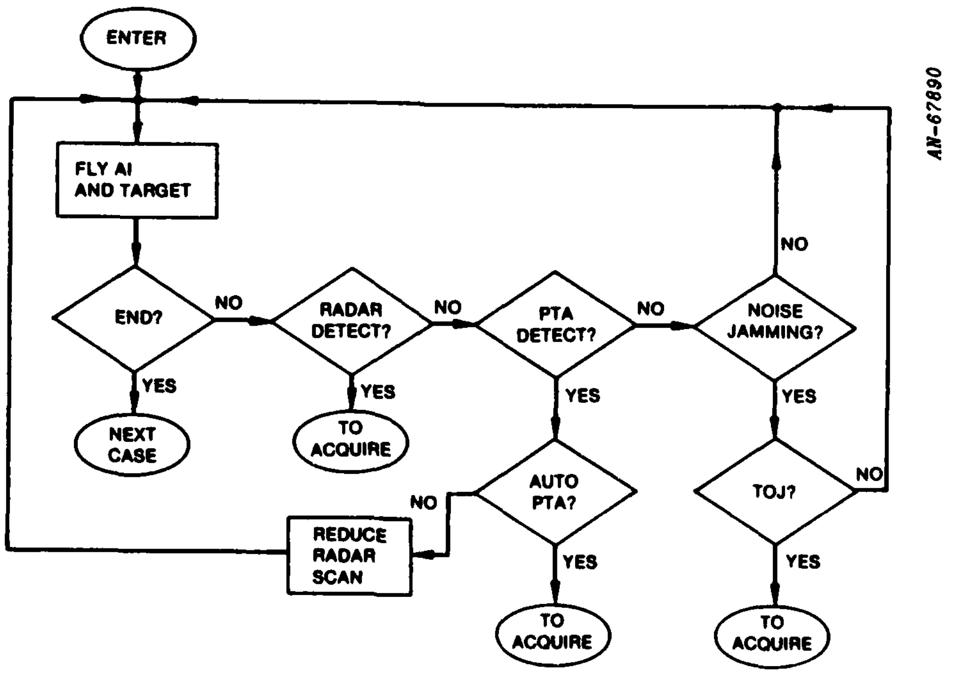


Figure 2.5. Detection Process Model

2.4.3 The Conversion Phase

After the target is detected, the pilot performs target identification using either on-board IFF equipment or guidance from the vectoring agency. Upon verifying that the contact is indeed his target, the pilot will attempt radar lock-on. The ENGAGE II simulation does not model the process of IFF or the pilot's actions between target identification and radar tracking. The user inputs a time delay (TSD2AC) that approximates the time lapse between radar detection and the beginniug of the radar lock-on attempt. This time delay also accounts for radar tracking settling time. The simulation requires that the signal-to-interference ratio exceed a user input value (ACRIT) in order that radar lock-on occur. The model logic for this acquisition phase is shown in Fig. 2.6.

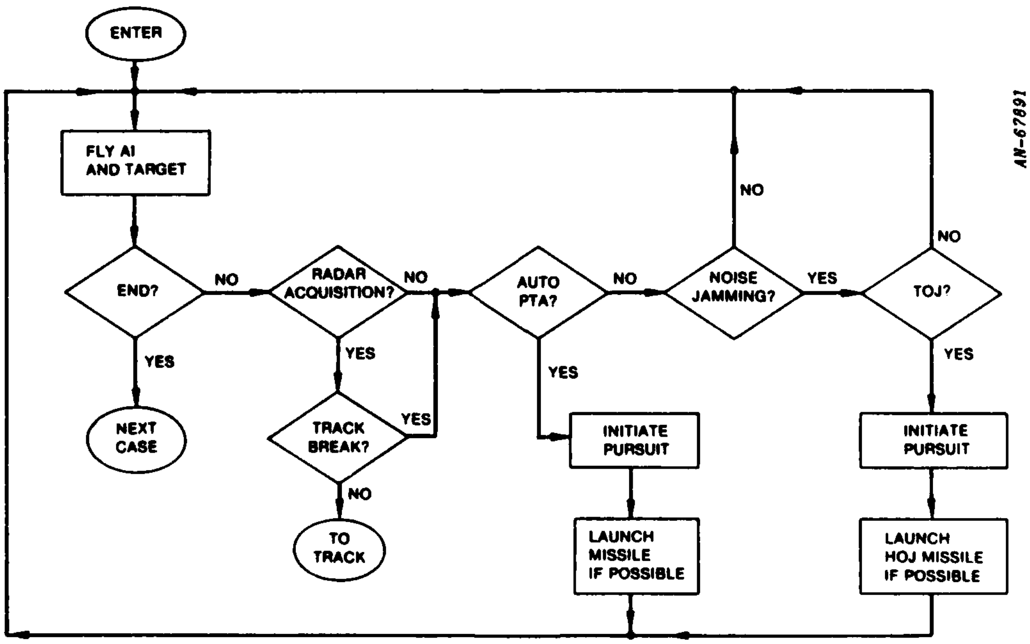


Figure 2.6. Acquisition Process Model

The model of AI conversion (to a position from which missiles may be launched) is handled in some detail in order to assess the impact of AI maneuverability. ENGAGE II considers the dynamic geometry and the missile flight characteristics to calculate the proper lead angle for missile firing. The user may assume a perfect fire-control radar, or allow ECM effects to distort the actual target position. This distortion is the third type of jamming allowed by the simulation. It is called Deceptive ECM (DECM), and modeled as a user input range, azimuth and/or elevation bias (BIASR, BIASAZ, and BIASEL). The biases are added to the true target values whenever the J/S exceeds TJEFF. The measured target position, which includes these errors, is used by the pilot to maneuver the AI and to determine when missile launch requirements are met. Once the target is within visible range (VISRNG) of the pilot, the bias errors are no longer included. Missile launch requirements depend on the present information available to the pilot, based on the quality of detection. The simulation includes the following missile launch modes:

- Home-on-Jam Launch Mode.
  This launch mode occurs when the AI radar detects a jamming signal using track-on-jam capability, but no successful Passive Track Adjunct detection or AI radar detection has yet been achieved. Both semi-active and actively-guided radar missiles with a home-on-jam capability may be launched in this mode. In this mode, only target angle is known.

- Passive Track Launch Mode.
  This launch mode occurs when the PTA is in autonomous mode, and has detected the target, but the AI radar has not yet locked-on to the target. Both actively-guided radar missiles and IR missiles may be launched in this mode. Both target range and angle are known in this mode.

- AI Radar Track Mode.

  This launch mode occurs when the AI radar has locked-on to the target. All radar missiles and IR missiles may be launched in this mode. Target range, angle, and range rate are all known in this mode. The model logic for this mode is shown in Fig. 2.7.

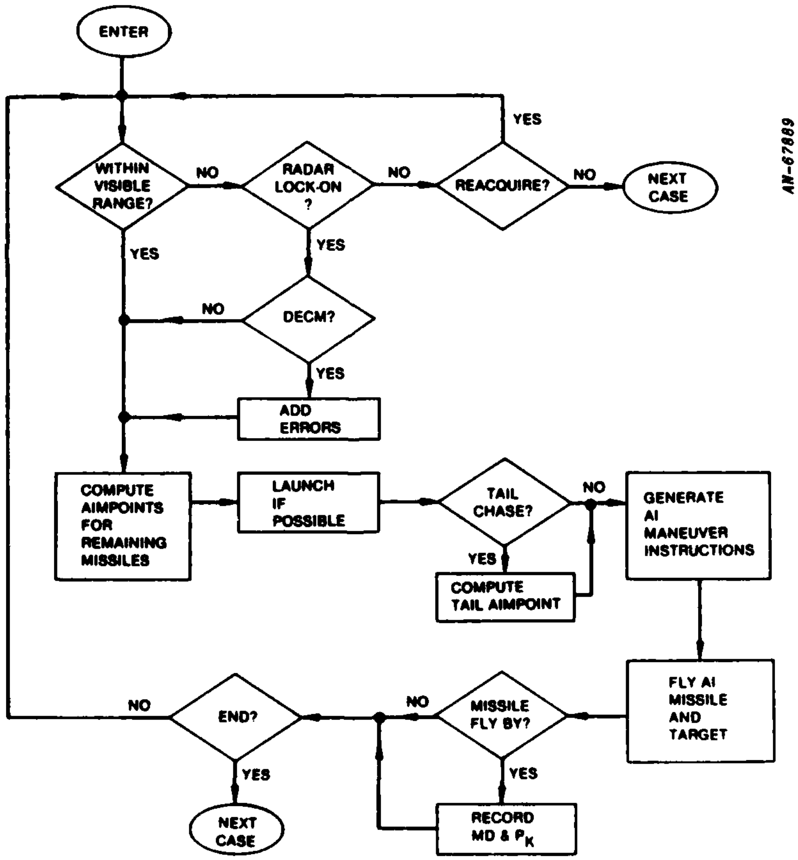


Figure 2.7. Track Process Model

Only one missile may be in-flight for any launch mode. However, if the launch mode changes, then a missile may be launched as soon as the new launch criteria are met, even if there are missiles still in flight from earlier launch modes.

There are two types of missiles on board the AI: IR and radar missiles (IRMIS and RADMIS). Each has a specific set of requirements which must be met before launch can occur; these launch requirements, which depend on both missile launch mode and missile type, are listed in Table 2.1. Both missile types must detect the target for a successful flight. Detection by the IR missile seeker requires the target line-of-sight to be within the scan limits of the seeker (GIMBMX(IRMIS)) and the range to the target to be within the IR missile detection range (table IRMSLRANGE.) The radar missile seeker lock-on requires that the target line-of-sight be within the scan limits of the seeker (GIMBMX(RADMIS)) and that the signal-to-interference ratio be adequate (SIRAAM). The model of the radar missile seeker is the same as that used for the AI high-PRF radar, described in Appendix A. All the cited sources of clutter and noise interference are considered. Missile launch is inhibited if the AI or the missile seeker are in their respective regions where mainlobe clutter (in-band mainlobe clutter) is present.

The ENGAGE II simulation handles two types of radar missiles-- those that require lock-on before launch (or shortly thereafter), and are semi-actively guided (AAMTYP=1), and those with active seekers that can lock on much after launch (AAMTYP=2). Both types of missiles must pass the same types of test for a successful flight. However, the semi-active type of missile must have seeker lock-on at the time of launch, while the active type of missile may wait until a specified time (TSAACQ) before the expected impact.

TABLE 2.1

MISSILE LAUNCH CRITERIA

HOME-ON-JAM LAUNCH MODE

Requirements for Radar Missile launch:

1. Radar missile is onboard.
2. Radar missile has Home-on-Jam capability (HOJ > 1).
3. No missile launched in Home-on-Jam launch mode is in flight.
4. Flight assessment is completed on last (if any) missile launched in Home-on-Jam launch mode.
5. Acceleration lift component is within AI launch G-Load limits (GMAXL).
6. Target is within maximum AI launch heading limits (ALHE).
7. Jammer-to-Noise ratio (J/N) at radar missile seeker is above threshold (J/N > THOJ).

TABLE 2.1 (CONT'D)

MISSILE LAUNCH CRITERIA

PASSIVE TRACK ADJUNCT LAUNCH MODE

Requirements for Radar Missile launch:

1. Radar missile is onboard.
2. No missile launched in Passive Track Adjunct launch mode is in flight.
3. Flight assessment is completed on last (if any) missile launched in Passive Track Adjunct launch mode.
4. Radar missile is actively guided (AAMTYP = 2).
5. Acceleration lift component is within AI launch G-Load limits (GMAXL).
6. Expected impact point is within maximum AI launch heading limits (ALHE).
7. Missile velocity at expected impact point is greater than target velocity.
8. Range to expected impact point is greater than mimimum launch range (RAAMMN).
9. Range to expected impact point is less than maximum missile range (maximum RAAM).

NOTE: The expected impact point for a missile launched in Passive Track Adjunct launch mode is the present target position.

TABLE 2.1 (CONT'D)

MISSILE LAUNCH CRITERIA

PASSIVE TRACK ADJUNCT LAUNCH MODE

Requirements for IR Missile launch:

1. IR missile is onboard.
2. No missile launched in Passive Track Adjunct launch mode is in flight.
3. Flight assessment is completed on last (if any) missile launched in Passive Track Adjunct launch mode.
4. Acceleration lift component is within AI launch G-Load limits (GMAXL).
5. Expected impact point is within maximum AI launch heading limits (ALHE).
6. Missile velocity at expected impact point is greater than target velocity.
7. Range to expected impact point is greater than mimimum launch range (RAAMMN).
8. Range to expected impact point is less than maximum missile range (maximum RAAM).
9. Target is within IR missile lock-on range (table IRMSLRANGE).
10. Target is within IR missile seeker gimbal limits (GIMBMX).

NOTE: The expected impact point for a missile launched in Passive Track Adjunct launch mode is the present target position.

TABLE 2.1 (CONT'D)

MISSILE LAUNCH CRITERIA

RADAR TRACK LAUNCH MODE

Requirements for Radar Missile launch:

1. Radar missile is onboard.
2. No missile launched in Radar Track launch mode is in flight.
3. Flight assessment is completed on last (if any) missile launched in Radar Track launch mode.
4. Acceleration lift component is within AI launch G-Load limits (GMAXL).
5. Expected impact point is within maximum AI launch heading limits (ALHE).
6. Missile velocity at expected impact point is greater than target velocity.
7. Range to expected impact point is greater than mimimum launch range (RAAMMN).
8. Range to expected impact point is less than maximum missile range (maximum RAAM).
9. Signal-to-Interference ratio (S/I) is above threshold (SIRAAM) for semi-actively guided radar missile type (AAMTYP = 1).
10. Target is within missile seeker gimbal limits (GIMBMX) for semi-actively guided radar missile type.

NOTE: The expected impact point for a missile launched in Radar Track launch mode is a lead pursuit aim point based on a non-maneuvering, constant-velocity target.

TABLE 2.1 (CONT'D)

MISSILE LAUNCH CRITERIA

RADAR TRACK LAUNCH MODE

Requirements for IR Missile launch:

1. IR missile is onboard.
2. No missile launched in Radar Track launch mode is in flight.
3. Flight assessment is completed on last (if any) missile launched in Radar Track launch mode.
4. Acceleration lift component is within AI launch G-Load limits (GMAXL).
5. Expected impact point is within maximum AI launch heading limits (ALHE).
6. Missile velocity at expected impact point is greater than target velocity.
7. Range to expected impact point is greater than mimimum launch range (RAAMMN).
8. Range to expected impact point is less than maximum missile range (maximum RAAM).
9. Target is within IR missile lock-on range (table IRMSLRANGE).
10. Target is within IR missile seeker gimbal limits (GIMBMX).

NOTE: The Expected Impact Point for a missile launched in Radar Track Launch Mode is a lead pursuit aimpoint based on non-maneuvering, constant velocity target.

The target, AI, and missile flight models are all three-degree-of-freedom models, and are described in Appendices D, E, and F. The guidance for the target is provided by the user, as a series of maneuvers. The guidance for the AI is dynamically determined at each time step based on a new maneuver aim point. The type of guidance for the missile is selected by the user.

2.4.4 The Attack Phase

In the ENGAGE II simulation, the interceptor aircraft continues the engagement until an end condition is encountered. Until then, the pilot launches missiles when he can, following a shoot-look-shoot philosophy. The user inputs a value for the time delay between the impact of one missile and the launch of the next missile (TSMI2L). This time delay accounts for attack assessment, trigger squeeze, and missile launch. ENGAGE II limits the number of missiles (these could also be considered salvos) with inputs by the user (AAMNUM(RADMIS) and (AAMNUM(IRMIS)).

After the launch of a missile, the simulation continues to monitor the flight of the missile for any type of failure, as well as to check for the closest approach. There are three general causes for in-flight missile failures.

- The missile flight exceeds the maximum guided flight time (TDMAX).

- The missile blind flight exceeds the maximum blind flight time (TDMIN).

- The missile flies below ground level.

Conditions which cause blind flight are similar to those which inhibit launch. These depend on the missile launch mode at the time the missile was launched. A list of conditions which must be met for guided (non-blind) flight are given in Table 2.2. When these conditions are not met, the flight is temporarily blinded. If it continues beyond an input maximum blind flight time (TDMIN), the flight must abort. For instance, if the missile is a semi-actively guided radar missile, the AI radar must continue to illuminate the target by keeping it within the AI radar gimbal limits. If the illumination fails, the missile flies blind for a specified time, then aborts. If the target illumination by the AI radar is reestablished before the maximum blind flight time, the missile flight continues. If the radar missile has an active seeker, the seeker need not detect and lock-on to the target until a user-specified time (TSAACQ) before the expected impact.

Missile flight assessment takes place after the missile has reached its closest approach to the target. This closest approach is defined as the first time the range rate between the missile and the target is zero or positive. The missile model integrates to provide the time (within 0.00001 seconds) when this happens; the range between the missile and the target at this time is called the miss distance. The user can add an aspect-dependent error to the miss distance (tables IRMISSERR and RADMISSERR). The resultant miss distance is then used to calculate the missile probability of kill, PKSS,

$$PKSS = 1 - 0.5^{(RLETHL/MISDIS)^2}$$

where RLETHL is the lethal radius of the target for this missile type (the radius with PK = 0.5); and MISDIS is the missile miss distance, including any user added error.

TABLE 2.2

MISSILE GUIDED - FLIGHT CRITERIA

Guided flight must meet the following requirements, until the missile reaches closest approach to the target or aborts. When missile flight does not meet these requirements, it is blind flight.

Radar Missile Launched in Home-on-Jam Launch Mode

1. Target is within missile seeker gimbal limits (GIMBMX).
2. Jam-to-Noise (J/N) ratio is above threshold (J/N > THOJ).

Radar Missile Launched in Passive Track Adjunct Launch Mode

1. Signal-to-interference ratio (S/I) is above threshold (SIRAAM) if time to expected impact is less than minimum time to acquire (TSAACQ).
2. Target is within missile seeker gimbal limits (GIMBMX) if time to expected impact is less than minimum time to acquire (TSAACQ).

IR Missile Launched in Passive Track Adjunct Launch Mode

1. Target is within IR missile lock-on range (table IRMSLRANGE).
2. Target is within missile seeker gimbal limits (GIMBMX).

Semi-Actively-Guided Radar Missile Launched in Radar Track Launch Mode

1. Signal-to-interference ratio (S/I) is above threshold (SIRAAM).
2. Target is within missile seeker gimbal limits (GIMBMX).
3. Target is within AI radar gimbal limits.

Actively-Guided Radar Missile Launched in Radar Track Launch Mode

1. Signal-to-interference ratio (S/I) is above threshold (SIRAAM) if time to expected impact is less than minimum time to acquire (TSAACQ).
2. Target is within missile seeker gimbal limits (GIMBMX) if time to expected impact is less than minimum time to acquire (TSAACQ).

IR Missile Launched in Radar Track Launch Mode

1. Target is within IR missile lock-on range (table IRMSLRANGE).
2. Target is within missile seeker gimbal limits (GIMBMX).

The probability of kill for the engagement, PK, is then

$$PK = 1 - \prod_{i=1}^{NMIS} (1 - PKSS)$$

where NMIS is the number of missiles launched during the engagement.

During the course of the attack phase, the target doppler may enter the region of the mainlobe clutter filter where the AI radar cannot track. The target may maneuver in a way which reduces the target RCS so that the signal-to-interference ratio falls below the radar threshold. In either of these cases, AI radar tracking may fail, and the tracking gates of the AI radar then usually enter a coasting phase, making use of its memory of the motion of the target. Various logic is used in AI radars to enable the tracking filters to pick up the target when it exits this clutter region. If the time is short, ENGAGE II allows the AI to continue to maneuver, modeling the effect of tracking memory. When the target exits this clutter region or the signal rises, tracking is assumed to reinitiate immediately and steering commands are immediately made available to the pilot. If, however, this coasting time is too long (TCOAST), then the AI radar must reacquire the target.

If guns are onboard, once the AI radar has locked-on and all missiles are launched, the AI will attempt to reach a gun-firing position. The area defining this position is illustrated in Fig 2.8. A similar pursuit area for IR missiles is also defined by the user. These areas are used by the model to help guide the AI to a stern attack. The AI maneuvering model is described in Appendix D.

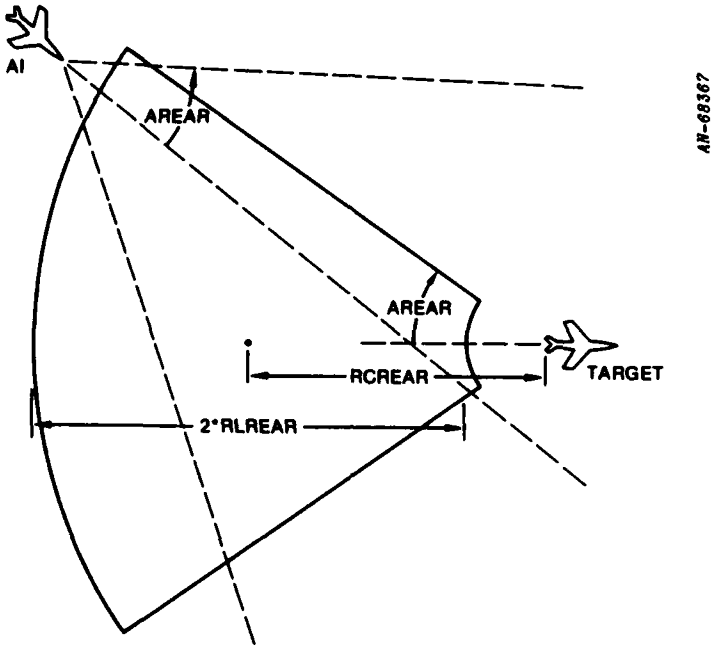


Figure 2.8. Pursuit Geometry

The following are engagement end conditions in the ENGAGE II model.

- The target exits the gimbal limits of the AI radar, unless the target is within visible range of the pilot (VISRNG). This end condition can occur in routines DETECT, ACQUIR, and TRACK.

- There are no guns onboard; all missiles have been launched and have reached their closest approach to the target. This end condition occurs in routine TRACK.

- There are guns onboard, and the AI has successfully reached gun position; and any missiles launched have reached their closest approach to the target. This end condition occurs in routine TRACK.

- The engagement time exceeds the maximum time (TABORT) allowed for an AI engagement. This end condition can occur in routines DETECT, ACQUIR, and TRACK.

- The target is beyond 90 degrees off the boresight of the AI heading, and the AI radar has not yet locked-on to the target. This end condition may occur in routines DETECT and ACQUIR.

2.5 MODEL USES AND LIMITATIONS

The model uses a missile flight table, containing missile range and velocity versus time, to determine when launch requirements have been met and to calculate the lead aim point for the AI maneuvers. There is a separate table for the radar missile and the IR missile. These tables must be appropriate to the geometry being simulated (launch velocity and altitude, target velocity and altitude). However, if these parameters vary by large amounts within an engagement, missile aim points and launch requirements may be incorrect, and launches may occur too early or too late.

Since the model assumes that the engagement is initiated as the result of GCI vectoring, the PD and PDC values are valid only when the assumptions used to establish the GCI positioning (HCAs and offsets) are valid. They would not be appropriate for "random" encounters, where the AI has received no guidance from GCI.

There are three ECM techniques in the model. These are used against the AI radar. Only the first, Noise Jamming, is modeled as affecting the missile seeker and then only to allow home-on-jam missile guidance. The others, Track Break and DECM, do not affect the radar missile seeker.

Missile flyout does not include any limitations other than time lag, propulsion level, and aerodynamic maneuverability of the missile. The user may simulate other errors which affect miss distance by using the target-aspect-dependent miss distance error tables (tables IRMISSTAB and RADMISSTAB).

The target can maneuver, but the aim points for the AI and missiles are not based on predictions of target acceleration; they use only target velocity.

The target maneuvers must be defined by the user before the engagement is run; to simulate any reactive maneuver, the user must run the engagement, decide on the time, magnitude, and direction of the maneuver, and rerun the engagement with altered target maneuver input directives.

Tactical options are rather rigid. For example, breakaway does not commence until all radar missiles are fired, no matter how close the target is. The AI continues to fly a lead collision course as long as there are missiles remaining. No attempt is made (until break away) to maintain stand-off from the target. The underlying assumption is that the target cannot shoot back.

The missile is "guided" all the way to the target, even if it is a lock-on-after-launch radar missile. This means that during the period between missile launch and seeker lock-on the missile flies according to the chosen guidance mode (proportional, pursuit or tail-chase) rather than using inertial or command guidance. These two guidance options could be added, but would require addition of a more detailed simulation of the AI fire control computer.

Missile launch decisions during PTA track assume that target speed but not direction is known. That is, no prediction of the target position at intercept is made, but a check to see that the missile velocity exceeds the target velocity is made.

The clutter is modeled using a backscatter coefficient of $\gamma \sin(\theta)$. This model is a reasonable approximation for clutter returns over ground terrain, but is not appropriate over water. Entirely new algorithms to calculate signal-to-clutter ratios would have to be developed to treat sea clutter.

3 ENGAGE II INPUT DESCRIPTION

This section describes the inputs for the program ENGAGE II. The methods of setting the input data are described in Sec 3.1; the general format of the data is given in Sec 3.2; and the input variables are described in Sec 3.3. Default values are mentioned in Sec 3.4.

3.1 SOURCES OF INPUT DATA

The input data may reside in one or several files, and may also be keyed in interactively during a run. Reading inputs from any unit (an input file or the terminal*) ends with the 3-letter word "END". At least one input file (unit 1) is expected, and terminal input (unit 5) is required. (Either could be the single input "END".) During interactive (unit 5) input, the user may indicate other input units (other files) to read. To do so, the user types:

FILE = Lunit

where "Lunit" is the logical unit number for the program to read. The program then reads from that logical unit until it encounters an "END", and returns to interactive mode. The user may input more data, select another input unit to read, or end the inputs and begin program calculations.

If additional input files are needed, the user must make any necessary file assignments before program execution.

For example:

The user has two input files for ENGAGE II. The f[illegible] is assigned as the standard input file on unit 1. The second file, MORDAT, contains additional input data. Before execution:

---

*The term "terminal" here refers to the primary input file. On a non-interactive system it may, in fact, be a card deck or disk file.

On the VAX: ASSIGN MORDAT.DAT FOR021

On the CDC: GET (TAPE21 = MORDAT)

After execution begins, unit 1 is read and then the user is prompted for input data. The user types:

FILE = 21

The program will read MORDAT input data, then prompt the user for more terminal inputs.

3.2 INPUT DATA FORMAT

The ENGAGE II input format is similar to FORTRAN NAMELIST, with the basic form:

NAME = Value UNITS

where:

NAME = is the parameter name (See Sec. 3.3)

Value = is the value to be assigned (decimal point not required for whole numbers)

and UNITS = name of units of input value

Blank spaces on each input line are ignored and may be used at will for readability. UNITS is optional, and if not given will default to the appropriate unit in the English units system (feet, pounds, seconds, radians) which are the internal units used in the program. The list of allowable UNITS names is given in Table 3.1 (page 69). The user may indicate default units even though this will not affect the value, to aid in documenting the data for later understanding.

An example is:

VI = 800 FPS

This will define the velocity of the Air Interceptor to be 800 ft/sec.

Some parameter names may be indexed by type. The form is then:

NAME (INDEX) = Value UNITS

where:

INDEX is the mneumonic identifier of the index of the parameter.

The possible indices are:

INDEX	PARAMETER
RADMIS	for the radar missile, and the radar missile seeker PRF mode
IRMIS	for the IR missile, and the IR missile pursuit area
AI	for the Air Interceptor
AI-HI	for the High PRF mode of the AI
AI-MED	for the Medium PRF mode of the AI
AI-LOW	for the Low PRF mode of the AI
GUNS	for the Gun pursuit of the AI

For example, if there are 3 radar missiles on board the AI, and 1 IR missile:

AAMNUM(RADMIS) = 3.
AAMNUM(IRMIS) = 1.

The input parameter descriptions in Sec. 3.3 indicate which, if any, of the index values are valid.

Some inputs are arrays. For these, a scalar input usually defines the number of elements in the array, and then the elements of the array are assigned to the array name. For example:

```
NHCA = 4
HCA = 0, 30 DEG, 150 DEG, 180 DEG
```

This will assign four Heading Crossing Angles, with values of 0, 30, 150, and 180 degrees. Note that DEG is used to define units different from the default, which is radians. A single value in the table can be reassigned by referencing the proper index. For instance, the third Heading Crossing Angle can be modified to 90 degrees for a subsequent run.

```
HCA(3) = 90 DEG
```

Comments may be added to the input stream to help the user document the data. Comments begin with a slash (/), and continue to the end of the input line. For instance:

```
/ These are the flight engagement parameters
NHCA = 1, HCA = 180 DEG      / Head on case only
```

The first line is all comment; the second line contains input data assignments followed by a comment. Note that more than one assignment may be made on the same line.

3.3 INPUT DATA DESCRIPTION

3.3.1 ENGAGE II Run Parameters

- RUN OPTIONS

  These options control the type of output generated by a program run.

IDRUN = The Run Identification number. This number is printed on all output.

KOUT = The diagnostic print flag.

- 0 = No diagnostic printout
- 1 = Diagnostic printout at Event Occurrences
- 2 = Diagnostic printout at Event Failures, with AI and target status
- 3 = Diagnostic printout at Event Failures, with AI, target, and missile status

IFLSUM = The Flight Summary output flag.

- 0 = No
- 1 = Yes

IEVSUM = The Event Summary output flag.

- 0 = No
- 1 = Yes

IEVHIS = The Event History output flag.

- 0 = No
- 1 = Yes

IFLPLT = The Flight Plot output flag. It will output the state vector at each time step for:

- The AI
- The target
- Each Missile in flight.

This could then be plotted by a postprocessor.

- 0 = No
- 1 = Yes

MSLMDL = The missile flight model flag.

- 0 = Three-Degree-of-Freedom missile flyout model
- 1 = Table lookup model. This model uses the input missile flight tables and the initial aim point, and assumes constant velocity.

- **FLIGHT CASE GEOMETRIES SELECTION**

These parameters define the number of engagements in the run, and describe the vectoring instructions and errors for each of these engagements. These parameters are illustrated in Fig. 2.3.

NHCA = The number of different Heading Crossing Angles to generate engagements. The maximum allowed is 7.

NOFF = The number of different offset distances for each Heading Crossing Angle. The maximum allowed is 11. NOFF is reset to the maximum allowed if the offset distribution flag, IOFDIS, is 0 or 1 (uniform or normal distribution.)

IOFDIS = The offset distribution flag. This flag defines how the different offset distances are determined.

- 0 = Uniform distribution for 11 offsets. Maximum offset is OFF(1) value.
- 1 = Normal distribution for 11 offsets. One sigma offset is OFF(1) value.
- 2 = User input offset distribution.

DLAG = The distance behind the target to which vectoring is desired.

RIO = The range at which the engagement begins (the vectored AI turns on the radar) when the Heading Crossing Angle is 0. degrees, the Tail chase geometry.

RIPI = The range at which the engagement begins (the vectored AI turns on the radar) when the heading crossing angle is 180. degrees, the Head-on geometry. The range for intermediate heading crossing angles is calculated using linear interpolation between RIO and RIPI.

TABORT = The maximum AI flight time for a single engagement.

HCA(I) = Heading crossing angles for I=1 to NHCA.

OFF(J) = Offset distances from J=1 to NOFF

- AIR INTERCEPTOR GEOMETRY

The following parameters describe the flight and maneuverability of the AI.

ACCMAX = The maximum acceleration of the AI in level flight. This is used to limit any requested velocity change for the AI.

ALTINT = The altitude of the AI at the beginning of the engagement.

DCCMAX = The maximum deceleration of the AI in level flight. This is used to limit any requested velocity change for the AI.

GLOAD = The maximum gravity force load of the AI.

GUNS = The Combat guns flag. If this flag is set to 1, the AI will attempt to maneuver to a successful gun-firing position after all missiles have been launched.

0 = No guns

1 = Combat guns on board - try for gun position

PRIOML = Missile launch priority. This flag determines which type of missile to attempt to launch first, at any given time, and may affect the AI maneuvering if IR missiles have launch priority and they are aspect dependent.

1 = Launch radar missiles before IR missiles if possible

2 = Launch IR missiles before radar missiles if possible

RRMAX = AI roll rate limit. If a maneuver is requested which requires a roll greater than RRMAX in the next time step, then the maneuver will not begin until enough time has passed for the full roll requested.

TSMI2L = The minimum time between one missile intercept (closest approach or missile abort) and the next missile launch. This is the time required for kill assessment. This time period is required for successive missiles launched in the same mode. It is not required between two missiles launched in different modes, such as one missile launched in Passive Track Adjunct Launch mode and another launched in Radar Track Launch mode. This is also the time period required between the beginning of radar track and the first radar track missile launch.

VI = The velocity of the AI at the beginning of the engagement.

VIMAX = The maximum allowed AI velocity.

VIMIN = The minimum allowed AI velocity.

VISRNG = The visual range of the pilot of the AI. This is not aspect dependent. It is used in Track mode to override the radar in close range, so the engagement does not end if the target is outside the radar gimbal limits. When the target is within the visual range of the AI, deceptive ECM does not perturb the AI's knowledge of the target position.

- PURSUIT DIRECTIVES

The rear area of pursuit is the region behind the target illustrated in Figure 2.8. The rear area of pursuit may be defined by index for guns, using index "GUNS"; and for IR missiles, with index "IRMIS". The "GUNS" area designates successful gun position for guns, and the "IRMIS" area provides an aimpoint for AI maneuvers for rear-aspect-dependent IR missile launches. (The following parameters are indexed. The index is "GUNS" for gun pursuit directives, and "IRMIS" for IR missile pursuit directives).

AREAR = The half angle of rear area pursuit. This angle, measured from the tail of the target, is the maximum angle of the AI off direct tail pursuit of the target. The same angle is the maximum allowed for the target off the nose of the AI.

RCREAR = The range to the center of the rear area of pursuit, behind the target.

RLREAR = The half-length of the region of the rear area of pursuit.

TSREAR = The time step for terminal approach for the rear area of pursuit. This time step is used by the model whenever the AI is within the effective pursuit radius of the target, no matter what the angle is. The effective pursuit radius is RCREAR+RLREAR.

- PASSIVE TRACK ADJUNCT PARAMETERS

The parameters describe the Passive Track Adjunct onboard the AI.

PAZGMB = Passive Track Adjunct azimuth gimbal limit. Gimbal limits are used in the PTA autonomous mode, once detection has occurred.

PELGMB = Passive Track Adjunct elevation gimbal limit.

PAZSCN = Passive Track Adjunct azimuth scan limit. Scan limits are used in the PTA detection process.

PELSCN = Passive Track Adjunct elevation scan limit.

PTAFLG = Passive Track Adjunct mode flag.

0 = No Passive Track Adjunct.

1 = Radar clue mode. In this mode, the radar scan time is redefined after successful PTA.

2 = Autonomous mode. In this mode, once detection has occurred, both radar and IR missile launch attempts may be made, and the AI may maneuver toward the target.

TSPTA = Passive Track Adjunct scan time step.

TSTA2R = New radar scan time step for radar detection after Passive Track Adjunct detection is successful. The radar scan time is modified only when the Passive Track Adjunct is in radar clue mode (PTAFLG = 1). This accounts for a smaller radar scan area, defined by the PTA information on target location.

TSTARE = The time step between the first successful Passive Track Adjunct return and a reasonable range estimate. A missile cannot be launched in PTA launch mode until this time period is past. This input is only used when the Passive Track Adjunct is in autonomous mode (PTAFLG = 2).

- AI ANTENNA

The following parameters describe the antenna of the AI radar. These define the radar scan time and angular limits of the scan. These antenna parameters are used to calculate the AI radar scan period, which is used when the detection criterion is based on cumulative PD (IDETYP = 2).

AZRATE = The AI radar azimuth scan rate

AZSCAN = The AI radar azimuth scan half-angle. The radar scans from minus to plus this value.

BARSEP = The elevation bar separation angle of the AI radar.

ELBARS = The number of elevation bars in an AI radar scan.

ELCTR = The center angle of the elevation scan of the AI radar.

TSHIFT = The time to shift bars in the AI radar scan. These antenna parameters are used to calculate the AI radar scan period, which is used when the detection criterion is cumulative PD (IDETYP = 2).

- AI RADAR DETECTION CRITERION

These parameters describe the AI radar detection and define the time steps used for the radar model.

DCRIT = AI radar detection criterion threshold. This is either:

the threshold for single scan detection if IDETYP = 1 or the threshold for cumulative detection if IDETYP = 2

ACRIT = AI radar acquisition criterion threshold for the signal-to-interference ratio. This threshold must be exceeded to initiate and continue AI radar track acquisition and AI radar track.

TSDET = The detection time step for single scan detection. (IDETYP = 1). Cumulative scan detection (IDETYP = 2) uses the calculated AI radar scan period.

TSD2AC = The time step between radar detection and track acquisition. This allows for the mechanical switching required by the AI radar to switch from scan mode to track mode.

TSACQ = The AI radar track acquisition time step.

TSTRK = The AI radar track time step.

TCOAST = The maximum coast time allowed in radar track. This is the maximum time the signal processor can update the track filter without new data. After this time, the radar must reacquire the target.

IDETYP = The detection type flag. This flag determines the method the radar uses to determine successful detection of the target.

1 = Detect on single scan Probability of Detection (K blips of M scans).

2 = Detect on cumulative Probability of Detection.

KBLIP = The number of successful single returns required in M scans for detection. This input is only used for single scan detection (IDETYP = 1).

MSCAN = The maximum number of scans allowed to get K blips for successful detection. The maximum allowed is 11. This input is only used for single scan detection (IDETYP = 1).

- AI RADAR

These are general AI Radar parameters.

GIMBAZ = The radar azimuth gimbal limit.

GIMBEL = The radar elevation gimbal limit.

PFA = The probability of false alarm.

RSCOPE = The scope-limited range of the radar. This hard limit requires the AI-to-target range to be within RSCOPE for any possible radar return.

TJEFF = The jammer effectiveness threshold. This input is only used if the target is in the track-break jamming mode (TJAM = 2) or Deceptive ECM jamming mode (TJAM = 3).

TOJ = AI radar Track-On-Jam flag.

0 = No Track-On-Jam capability.

1 = Track-On-Jam capability onboard AI radar.

TTOJ = The Track-On-Jam threshold. This input is only used if the radar has Track-On-Jam capability (TOJ = 1). The jam-to-noise ratio must be above this threshold for the AI Radar to detect in track-on-jam mode.

VCMIN = The half-width of the altitude clutter filter.

VTHMIN = The half-width of the mainbeam clutter filter for high PRF.

VTMMIN = The half-width of the mainbeam clutter filter for medium PRF.

- AI RADAR AND SEEKER PERFORMANCE PARAMETERS

The following parameters are general radar parameters for both the AI Radar and the Radar Missile Seeker. These parameters are indexed. The index is "AI" for the AI radar, and "RADMIS" for the missile seeker.

ALAMB = The radar wavelength.

AVGPWR = The average transmitter power times the duty factor.

TGML = The transmitter mainlobe gain above isotropic.

RGML = The receiver mainlobe gain above isotropic.

RGBL = The receiver backlobe gain above isotropic.

TBMW = The transmit mainlobe beamwidth at the 3 DB point.

RBMW = The receive mainlobe beamwidth at the 3 DB point.

SIGMAX = The signal at the antenna face causing gain compression.

FNOISE = The receiver noise factor referenced to input.

GAMMA = The ground backscatter coefficient for this scenario.

ALOSSJ = The input loss at the receiver for a jamming signal.

- AI RADAR AND SEEKER PRF PERFORMANCE PARAMETERS

The following parameters are dependent on the PRF type. The AI radar can have any combination of three PRF types: high, medium, and low. The missile seeker is assumed to have only a single PRF type, high. These parameters are indexed. The index is:

AI-HI for the high PRF type of the AI radar;
AI-MED for the medium PRF type of the AI radar;
AI-LOW for the low PRF type of the AI radar;
or RADMIS for the high PRF type of the missile seeker.

PRFTYP = The PRF type availability flag. This flag enables or disables a particular PRF type.
0 = Disable this PRF type.
1 = Enable this PRF type.

RZERO = The range at which the target is detected under free space conditions, when the target RCS value is SIGMA0.

SNZERO = The Signal-to-Noise ratio at which the detection at range RZERO occurs.

SIGMA0 = The Radar Cross Section of the target for the given RZERO and R1 conditions.

R1 = The range at which the target is detected under conditions with in-band clutter, when the target RCS value is SIGMA0.

GAMMA1 = The ground backscatter coefficient for R1 conditions.

VI1 = The radar velocity for R1 conditions.

ALT1 = The radar altitude for R1 conditions.

SCV = The sub-clutter visibility. This is the negative of feedthrough.

TAU = The pulse length.

- AAM SEEKER

These parameters describe the seeker on the radar missile.

AAMTYP = The missile seeker type flag.

1 = Lock on before launch (LOBL). This is a semi-active missile type, requiring AI illumination on the target during missile flight.

2 = Lock on after launch (LOAL). This is an active missile type, independent of AI direction once it is launched.

CMBAAM = The half-width of the seeker mainbeam clutter notch.

HOJ = The Seeker Home-On-Jam flag. Only radar missiles with this capability can be launched during Track-on-Jam launch mode.

0 = No Home-on-Jam capability.

1 = Home-on-Jam capability available.

SIRAAM = The missile seeker threshold for the signal-to-interference ratio.

THOJ = The Home-On-Jam threshold. This input is only used if the seeker has Home-On-Jam capability (HOJ = 1.). The Jam-on-Noise ratio at the missile seeker must be greater than this threshold for guidance for a Home-on-Jam launched missile.

TSAACQ = The time step before expected impact for seeker acquisition for an active (LOAL) type seeker.

- AAM LAUNCH CRITERIA

These parameters describe the missiles onboard the AI. (The following parameters are indexed. The index is "RADMIS" for radar missiles, and "IRMIS" for IR missiles.)

AAMNUM = The initial number of missiles onboard. The maximum is 20.

ALHE = The maximum allowed launch heading error.

GIMBMX = The gimbal limit of the missile. This angle is measured from the velocity vector of the missile or of the AI at launch time. The angle to the target must be within this limit for guided flight.

GMAXL = The maximum gravity load of the AI at the time of the missile launch.

RAAMMN = The minimum flight range of the missile for effective guidance.

RLETHL = The lethal radius of this missile against this target. This is the radius around the target with PK=0.5; it is independent of target aspect.

TDMIN = The maximum time without guidance before the missile will abort. This is the length of time the missile tracking algorithms can continue without new data.

TDMAX = The maximum guided flight time of the missile.

- AAM FLIGHT TABLE

These missile flight tables are used to determine missile air points for launch. These tables can be calculated using the missile input data in Secs. 3.3.4 and 3.3.5 in utility program AATEST. AATEST is described in Appendix H. (The following parameters are indexed. The index is "RADMIS" for radar missiles, and "IRMIS" for IR missiles).

AAMFTN = The number of entries in the AAM flight table. The maximum number allowed is 25.

TDAAM = Time increment between flight table entries.

RAAM(I) = AAM flight table range I.

VAAM(I) = AAM velocity at range RAAM(I). The first entry in the table is at missile launch, where RAAM(1)=0.0 and VAAM(1)=VI (the velocity of the AI).

- TARGET GEOMETRY

The following parameters describe the target, along with the target-aspect-dependent tables.

ALTTGT = The altitude of the target at the beginning of the engagement.

ASPDIR = IR aspect-dependency flag. This flag is used to determine if it is better for the AI to maneuver to a pursuit position to attempt to launch IR missiles.

 0 = Little or no aspect dependency (pursuit maneuver not required)

 1 = Large IR aspect dependency (indicates pursuit as best maneuver)

BIASAZ = The bias error in azimuth. This input is only used if the target uses deceptive jamming (TJAM = 3)

BIASEL = The bias error in elevation. This input is only used if the target uses deceptive jamming (TJAM = 3)

BIASR = The bias error in range. This input is only used if the target uses deceptive jamming (TJAM = 3)

BWJAM = The jammer bandwidth. This input is only used if the target has some jamming capability (TJAM is greater than 0)

TJAM = The target jammer flag.

0 = No jamming

1 = Noise jamming (delays radar detection)

2 = Track break (delays radar acquisition)

3 = Deceptive ECM (bias errors affect radar track)

VT = The velocity of the target at the beginning of the engagement.

3.3.2 Target Maneuver Inputs

The target maneuver input table is indicated by the table name, MANEUVER; then each maneuver follows as a set of 5 parameters. The table ends with the word END. The 5 parameters needed to describe a maneuver are:

- The duration of the maneuver
  (Default units are seconds)
- The direction of the maneuver
  (Direction is defined as :
  0 deg is right
  90 deg is down
  180 deg is left
  270 deg (-90 deg) is up)
  (Default units are radians)
- The magnitude of the maneuver (velocity-vector turn-rate)
  (Default units are radians/second)
- The longitudinal acceleration during the maneuver
  (Default units are feet/second/second)
- The bank angle (not actually used by current program)
  (Default units are radians)

Up to 30 maneuvers may be stored for the target. If the target completes all maneuvers in the maneuver table, it begins again at the beginning of the table.

The following example will fly the target along a straight path for the duration of the engagement.

```
MANEUVER
99999 SEC, 0 DEG, 0 DGPS, 0 FPSS, 0 DEG
END
```

The following example will fly the target in a continual sinusoidal path.

```
MANEUVER
10 SEC, 0 DEG, 9 DGPS, 0 FPSS, 0 DEG,
20 SEC, 180 DEG, 9 DGPS, 0 FPSS, 0 DEG,
10 SEC, 0 DEG, 9 DGPS, 0 FPSS, 0 DEG,
END
```

In this example, units were used on all values even though "SEC" and "FPSS" are not necessary.

3.3.3 Target Aspect Tables

All target aspect-dependent tables have the same format. Each table is immediately preceded by a table heading card and ends with an "END" card. The table heading card format is:

TABLENAME (UNITS)

where:

	TABLENAME	is the name of the aspect table
and	UNITS	is the name of the units of the data in the table.

Allowable units names are given in Table 3.1 (page 69).

Aspect table names are:

RCSTABLE	Target Radar Cross Section (RCS) table
ERPTABLE	Jammer ERP table
IRMSLRANGE	IR missile lock-on range table
IRMISSERR	IR missile miss distance error term table
RADMISSERR	Radar missile miss distance error term table
PTATABLE	Passive Track Adjunct lock-on range table

For example:

PTATABLE (NMI)

This indicates that the Passive Track Adjunct lock-on range table follows, and the table data will be in nautical miles.

The user provides table data for equally spaced azimuth values along a single elevation angle, repeating if there are several elevation angles. Azimuth is measured from the nose of the target, so 0 degrees is in front of the target, 180 degrees is behind the target. Elevation is defined as positive above the target, and negative below. The target is assumed to be symmetrical in azimuth about 0 degrees.

The order of the data in the table is defined by the table parameters for that table. The table data is grouped by elevation, then within elevation, by azimuth. Table parameters define the number of table values for a single elevation, and the number of different elevation angles represented in the table. The table parameters follow the table heading card. The table parameters are:

NAZ = Number of table values in azimuth per elevation cut (These values are assumed to correspond to azimuth angles from 0 to 180 degrees.)

NEL = Number of elevation cuts

ELMIN = Minumum elevation angle (first EL cut)

ELSTP = Angle increment between adjacent elevation cuts

TABLE = Table data

SCALE = Scaling factor for all table entries (Default is 1.0)

Table data is stored by azimuth angle, then elevation cut.

```
    TAB(I)
             (For AZ from 0 to 180 degrees for each EL cut)
      I = 1 TO NAZ        For 1st EL cut at EL = ELMIN
        = NAZ+1 TO 2*NAZ  For 2nd EL cut at ELMIN+ELSTP
        = 2*NAZ+1 TO 3*NAZ
                          For 3rd EL cut at ELMIN+2*ELSTP
        = ...
        = (NEL-1)*NAZ+1 TO NEL*NAZ
                          For NEL-TH EL cut at ELMIN+(NEL-1)*ELSTP
```

Table data ends with "END". The total number of entries in the table is NEL*NAZ.

When all parameters have been provided, a final "END" corresponds to the end of an aspect table.

Example: Sample RCS table, with data at every 45 deg in azimuth, and at 3 different elevation angles, -10, 0, and 10 deg. Input data is in DBSM.

```
RCSTABLE (DBSM)
   NAZ = 5
   NEL = 3
   ELSTP = 10.DEG
   ELMIN = -10. DEG
   TABLE = 3, 2, 1, 2, 3
           4, 3, 2, 3, 4
           3, 2, 1, 2, 3
   END
END
```

Note that units must be defined when not standard (FPS). Tables may be single-valued, or may have data for only a single elevation cut.

Example:

```
IRMISSERR (FT)
   NAZ = 1
   NEL = 1
   TABLE = 1., END
END
```

This places a single value, one foot, in the IR missile miss distance error term table. The units name is not necessary, since the default is feet.

3.3.4 Missile Input Data

The following input parameters control the guidance, propulsion, aerodynamics, and integration of missile flight trajectories in ENGAGE II.

All of these parameters have an index for missile type, either "RADMIS" or "IRMIS". The stage-dependent parameters (not the guidance parameters) may also have an optional "gang" unit name, e.g.: CPTHRST (IRMIS) (LB) = 10000,2000. If a "gang" unit name is not used, individual stage values may still use unit names, e.g.: CPTHRST (IRMIS) = 10000 LB, 2000 LB.

- RUN CONTROL

  (The following input is a stage variable)

  DTINT = step size for trajectory integration (for each stage)

- MISSILE PHYSICAL DESCRIPTION

  (The following inputs are stage variables)

  CPTHRST = The initial vacuum thrust for each stage. If the sign given to the thrust value is positive, the constant-thrust model is used. If the thrust is input with a negative sign, the constant-acceleration thrust model is used.

  CPMASSI = The initial stage weight. For each stage, this value corresponds to the total vehicle weight, including all succeeding unburned stages. The number of stages each missile type has is determined by the number of non-zero CPMASSI values input for that missile type.

  CPMASSF = The final stage weight. Again, the value of this parameter is the total vehicle weight, including all succeeding unburned stages.

  CPNEA = The nozzle exit area for each stage.

  CPTB = The burning time for each stage.

  TCOB4I = The coasting time for each stage preceding ignition of that stage. The nominal value for each stage is 0.

TCOABO = The coasting time for each stage following burnout of that stage. The nominal value for each stage but the last is zero; the last stage is assigned an arbitrarily long post-burnout coasting interval.

CPAREA = The aerodynamic reference area for each stage.

CPCONE = The cone half-angle for each stage. This parameter is required only when the functional expression is to be used to calculate the axial force coefficient C_x of the corresponding stage. If a CXCPKB (and CXCPKC, if there exists a stage coasting segment) table is input for the determination of C_x for the Kth stage, this input parameter is not required for that stage.

CX2CP = The induced axial force coefficient C_{x_2} for each stage. This parameter is required only when the functional expression is to be used to calculate the axial force coefficient C_x of the corresponding stage.

CN1CP = The first-order normal force coefficient C_{N_1} for each stage. This parameter is required only when the functional expression is to be used to calculate the normal force coefficient C_N of the corresponding stage.

CN2CP = The second-order normal force coefficient C_{N_2} for each stage. This parmaeter is required only when the functional expression is to be used to calculate the normal force coefficient C_N of the corresponding stage.

CXCPKB (TABLE) = A table of axial force coefficient $C_x(M,A)$ for the Kth stage during burning, where M is Mach number and A is angle-of-attack. When this table is input, it is used in preference to the functional expression for C_x, and the parameters CPCONE and CX2CP need not be input for the Kth stage. The format for this table is described later.

CXCPKC (TABLE) = A table of axial force coefficient $C_x(M,A)$ for the Kth stage during coasting. If the Kth stage contains no coasting segment, then this table may be omitted. The format for this table is described later.

CNCPK (TABLE) = A table of normal force coefficient $C_N(M,A)$ for the Kth stage, where M is Mach Number and A is angle-of-attack. When this table is input, it is used in preference to the functional expression for C_N, and the parameters CN1CP and CN2CP are not needed for the Kth stage. The format for this table is described later.

ANMAXCP = The limiting acceleration a_{Nmax} for each stage normal to the missile's longitudinal axis, corresponding to a structural load limit.

ALFMXCP = The angle-of-attack limit $_{max}$ for each stage.

DELTAC = The time-lag used in estimating target position and velocity. To compute the guidance command at time T, the target's true state at T - DELTAC is used, then extrapolated forward to time T, and the guidance computation based on this state. Strictly speaking, this input is a guidance parameter. However, since it is input as a function of stage number as well as missile type, it is grouped with the missile physical description inputs.

- GUIDANCE PARAMETERS

GNAV1 = The guidance gain for pursuit or proportional guidance, minimum gain for tail-chase proportional guidance.

GNAV2 = The maximum guidance gain for tail-chase proportional guidance.

ATANG = The tail-chase desired approach angle in tail-chase proportional guidance.

RMAX = The maximum phantom target offset in tail-chase proportional guidance.

RMIN = The minimum phantom target offset in tail-chase proportional guidance.

KGYDE = The guidance model selector.

0 = pursuit guidance

1 = proportional guidance

2 = tail-chase guidance

INCLG = Guidance gravity flag. If zero, the guidance command is satisfied using aerodynamic/thrust forces only (gravity acts as a perturbation). If positive, gravity is included vectorially in satisfying the guidance command.

3.3.5 Missile Aerodynamic Table Input Format

Each table is immediately preceded by a table heading card. The format is as follows:

TABLENAME (INDEX) (UNITS) where:

TABLENAME is the name of the table

INDEX is the missile index

and UNITS is the name of the units of the angle-of-attack data in the table. Allowable units names are given in Table 3.1 (page 69). The default, if UNITS is not given, is radians.

The table names are:

	Missile Stage 1	Missile Stage 2	Missile Stage n (n = 3 to 7)
C_x during thrusting	CXCP1B	CXCP2B	CXCPnB
C_x during coasting	CXCP1C	CXCP2C	CXCPnC
C_N	CNCP1	CNCP2	CNCPn

The missile index values are:

RADMIS	Radar Missile
IRMIS	IR Missile

The data to be tabulated for aerodynamic tables is:

1. Dimensionless Mach number (M)
2. Angle of attack (A) (UNITS, if given, refer to this data)
3. Dimensionless aerodynamic coefficient (C)

The data should appear in the following order:

M1, A11, C11, A12, C12, ... A1n1, C1n1, END
M2, A21, C21, A22, C22, ... A2n2, C2n2, END
.
.
.
Mr, Ar1, Cr1, Ar2, Cr2, ... Arnr, Crnr, END, END

where:

r is the number of Mach values in the table,

and n is the number of A,C pairs for each Mach value.

Both Mach number and Angle-of-Attack entries must be arranged in monotonically increasing order. The word END signals the end of data for a particular Mach value, with another END signifying the end of the table. The program uses linear interpolation between adjacent values of Mach number, while parabolic interpolation is used in angle-of-attack, requiring at least three A,C pairs for each value of M. The number of A,C pairs associated with each M need not be constant, nor need the values of the A entries be identical for different values of M. Extrapolation will be used if, during execution, the table is searched with values for the independent variable M or A that range beyond the values included in the table. For best accuracy, however, the tabulated entries should encompass the entire expected range of values of these variables.

The total length of all input aerodynamic tables combined may not exceed 800 values.

Example:

```
CXCP1B (IRMIS) (DEG)
1.25,    0.,.9,  3.,1.1,  6.,1.7,   12.5,4.0,   END
1.75,    0.,.9,  3.,1.1,  6.,1.6,   12.,3.7,    END
2.00,    0.,.8,  3.,1.0,  6.,1.5,   12.5,3.5,   END
3.00,    0.,.8,  3.5,.9,  7.,1.3,   14.0,3.0,   END
4.00     0.,.7,  3.8,.8,  7.5,1.2,  15.0,2.5,   END
END
```

3.4 INPUT VALUE DEFAULTS

The program has stored default values for all input variables. The default value for all ENGAGE II Run Parameters (Sec 3.3.1) is zero, except for two run options, IEVHIS and IFLSUM:

IEVHIS = 1

IFLSUM = 1

Each target aspect table (Sec 3.3.3) is a single-valued table with a single default value. These defaults are:

RCS Table: RCSTABLE = 1.

ERP Table: ERPTABLE = 1.

IR Missile Lock-On Range: IRMSLRANGE = 0.

IR Missile Miss Distance Error: IRMISSERR = 0.

Radar Missile Miss Distance Error: RADMISSERR = 0.

Passive Track Adjunct Lock-On Range: PTATABLE = 0.

The missile input data (Sec. 3.3.4) defaults are zero, with the following exceptions:

GNAV1 = 2

GNAV2 = 8

ATANG = 30 DEG

RMAX = 30 NMI

RMIN = 2 NMI

CPTHRST(1) = 5000

CPMASS1(1) = 1000

CPMASSF(1) = 500

CPNEA(1) = 1

CPTB(1) = 1

TCOABO(1) = 99999

CPAREA(1) = 5

CPCONE(1) = 10 DEG

CX2CP(1) = 0.0002 DG-2

CN1CP(1) = 0.05 DG-1

CN2CP(1) = 0.001 DG-2

ANMAXCP(1) = 50 G

ALFMXCP(1) - 15 DEG

DELTAC(1) = 0.1

DTINT(1-7) = 0.25

These defaults hold for both RADMIS and IRMIS missile types. The default condition for the missile aerodynamic tables (Sec. 3.3.5) is null, i.e., no tables present.

TABLE 3.1

CURRENT VALID UNIT NAMES FOR ENGAGE II

NAME	DEFINITION	CONVERSION FACTOR	CONVERTS TO
CM	centimeters	0.032808330	feet
DEG	degrees	0.017453292	radians
DG-1	1./degrees	57.295780	1./radians
DG-2	1./degrees**2	3282.8064	1./radians**2
DGPS	degrees/sec	0.017453292	radians/sec
FPS	feet/sec	1.0	feet/sec
FPSS	feet/sec**2	1.0	feet/sec**2
FT	feet	1.0	feet
G	gravities	32.173981	feet/sec**2
HR	hours	3600.0	seconds
KFT	kilofeet	1000.0	feet
KG	kilograms	2.2046223	pounds
KM	kilometers	3280.8330	feet
KMPH	kilometers/hr	0.91134250	feet/sec
KNTS	knots	1.6889722	feet/sec
LB	pounds	1.0	pounds
M	meters	3.2808330	feet
MIN	minutes	60.0	seconds
MPH	miles/hr	1.4666667	feet/sec
MPS	meters/sec	3.2808330	feet/sec
MPSS	meters/sec**2	3.2808330	feet/sec**2
MRAD	milliradians	0.001	radians

TABLE 3.1 (CONT'D)

CURRENT VALID UNIT NAMES FOR ENGAGE II

NAME	DEFINITION	CONVERSION FACTOR	CONVERTS TO
MSEC	milliseconds	0.001	seconds
NEWT	Newtons	0.2248089	pounds
NMI	nautical miles	6080.2998	feet
RAD	radians	1.0	radians
SEC	seconds	1.0	seconds
SQCM	centimeters**2	0.0010763865	feet**2
SQFT	feet**2	1.0	feet**2
SQIN	inches**2	0.006944444	feet**2
SQM	meters**2	10.763865	feet**2
WATT	Watts	1.0	Watts
DB	decibels (dB)	10.*L(v)	-
DBSM	dB/sq.meter	0.929034*L(v)	feet**2
DBSF	dB/sq.foot	10.*L(v)	feet**2
DBWT	dB/Watt	10.*L(v)	Watt

L(v) = Log10(value)

4 SAMPLE PROBLEM

The sample problem we present here is intended to assist the user in understanding the input requirements for the model. The input data do not correspond to any real systems. The actual input data appear in the tables exactly as they would in the data file(s) used during program execution. In fact, they are the actual input data used to create the example outputs presented in Sec. 5.

The variables which control the types of output and the initial conditions are shown in Table 4.1. Three types of output files (described in Section 5) are requested. Five cases will be run, starting nose-on, then every forty-five degrees around to tail-on. Three offsets are specified for each crossing angle, giving a total of fifteen trials. The initial range (AI to target) will be between 40 and 25 nautical miles, depending on the crossing angle. No single trial will last longer than 700 seconds.

TABLE 4.1

OUTPUT CONTROL AND VECTORING INPUTS

```
/  Sample Problem for ENGAGEII
/  Maneuvering Target with Track-Break Jammer
IDRUN = 20
IFLSUM = 1, IEVSUM = 1, IEVHIS = 1
/   Flight engagement parameters
NHCA = 5
HCA = 180DEG,145DEG,90DEG,45DEG,0DEG
IOFDIS = 2, NOFF = 3, OFF(1) = -5000.,0.,5000.
RIO = 25.NMI, RIPI = 40.NMI
TABORT = 700.SEC
```

The inputs describing the interceptor are contained in Table 4.2. The AI has an initial velocity of 800 fps and is capable of 6.5G turns. Launch priority is radar missiles first, then IR missiles, then guns. Pursuit directives are given for both IR missiles and guns. The visible range is set at five nautical miles: this is important because no checks on radar lock-on are made within visible range (except those necessary to fire semi-active missiles.) Deceleration is limited to 20 ft/sec/sec, which can be a significant limitation when attempting to obtain a gun firing position to the rear of the target.

TABLE 4.2
INTERCEPTOR INPUTS

/ AI geometry:
ALTINT = 5500.
GLOAD = 6.5G
RRMAX = 3.14159
ACCMAX = 40.
DCCMAX = -20.
TSMI2L = 5.
VI = 800.
VIMAX = 1000.
VIMIN = 575.
VISRNG = 5.NMI
GUNS = 1
PRIOML = 1

/ pursuit directives:	/ pursuit directives FOR GUNS:
AREAR(IRMIS) = 30.DEG,	AREAR(GUNS) = 20.DEG
RCREAR(IRMIS) = 2.NMI,	RCREAR(GUNS) = .2NMI
RLREAR(IRMIS) = 1.NMI,	RLREAR(GUNS) = .1NMI

The AI is equipped with two sensors: a radar and a passive djunct. The performance of these two sensors is described in Table 4.3. The first two segments of the Table include the timing inputs. The time steps during acquisition (TSACQ) and track (TSTRK) are not actually radar parameters, but simulation time steps. The user must choose time steps based on the fidelity required, realizing that smaller time steps will increase the run time. One second has been found to be a good compromise for subsonic intercepts. As the target or AI velocities are increased, TSTRK must be reduced. There is a third time step (TSREAR, not used in this example) which may be used during the conversion to rear-hemisphere IR or gun firing positions. High line-of-sight rates may occur during these phases, and it may be necessary to use time steps as small as .1 to .2 seconds.

The radar has both high- and medium-PRF modes. The high-PRF mode performs better in a clutter-free environment (RZERO(AI-HI)), and the medium-mode is superior in clutter (R1(AI-MED)). The variables beginning with AVGPWR and ending with ALOSSJ are used for main-lobe clutter and jamming calculations (see Appendices A and B). The scope-limited detection range is 60 nautical miles. The scan pattern is four elevation bars by ±60 degrees in azimuth. Most radars have several optional settings for RSCOPE, AZSCAN and ELBARS, and a continuous range for ELCTR. These would be set according to where the controlling agency advised the pilot to look for the target.

The AI radar has a track-on-jam option(TOJ=1), but this cannot be used in this example since the jamming is a track-breaker. Track-on-jam is considered to be usable only against noise jamming. TJEFF is the threshold J/S ratio the jamming must exceed in order to break track.

TABLE 4.3

AI SENSOR INPUTS

```
/   detection and acquisition criteria
DCRIT  =.5
ACRIT = 21.
TSD2AC = 4.
TSACQ = 1.
TSTRK = 1.
TCOAST = 10.
IDETYP = 2
/  passive track adjunct parameters:
PTAFLG = 2
TSPTA = 4.
TSTA2R = 2.
TSTARE = 4.SEC
PAZSCN = 60. DEG
PELSCN = 30. DEG
PAZGMB = 60. DEG
PELGMB = 30. DEG
/ medium-PRF radar parameters      /  High-PRF parameters:
RZERO(AI-MED) =21.9NMI,            RZERO(AI-HI) = 28.4NMI
SNZERO(AI-MED)=20.,                SNZERO(AI-HI)=20.
SIGMA0(AI-MED) = 5.SQM,            SIGMA0(AI-HI) = 5.SQM
R1(AI-MED) = 16.5NMI,              R1(AI-HI) = 4.3NMI
GAMMA1(AI-MED) = .15,              GAMMA1(AI-HI) = .15
VI1(AI-MED) = 1300.,               VI1(AI-HI) = 1300.
ALT1(AI-MED) = 1000.,              ALT1(AI-HI) = 1000.
SCV(AI-MED) = 55.DB,               SCV(AI-HI) = 85.DB
TAU(AI-MED) = .0013MSEC,           TAU(AI-HI) = .002MSEC
PRFTYP(AI-MED) = 1,                PRFTYP(AI-HI) = 1
```

TABLE 4.3 (CONT'D)

AI SENSOR INPUTS

```
/ parameters common to both modes:
AVGPWR(AI) = 400.WATT
ALAMB(AI)  = 3.CM
TGML(AI) = 2250.
RGML(AI) = 2250.
RGBL(AI) = .11
TBMW(AI) = 4.DEG
RBMW(AI) = 4.DEG
SIGMAX(AI) = .0001
FNOISE(AI) = 2.5
ALOSSJ(AI) = .03
/ GAMMA FOR THIS RUN:
GAMMA(AI)=.015
TJEFF = 10.
TTOJ = 10.
TOJ = 1
PFA = 8.E-7
RSCOPE = 60.NMI
VCMIN =  60.MPS
VTHMIN = 60.MPS
VTMMIN = 60.MPS
/   antenna
GIMBAZ = 60.DEG
GIMBEL = 60.DEG
AZRATE = 96.DGPS
AZSCAN = 60.DEG
BARSEP = 2.DEG
ELBARS = 4
ELCTR = -2.DEG
TSHIFT = .2
```

The initial altitude for the target is 500 ft below the AI (ALTTGT in Table 4.4) and it has a 200 fps speed disadvantage. It is equipped with a track-break jammer (TJAM = 2) with a 10 MHZ bandwidth (BWJAM). The jamming is very directional, as shown in ERPTABLE. Both the passive track adjunct and the IR missile have no nose-on capability. It should be noted here that PTATABLE, IRMSLRANGE, IRMISSERR and RADMISSERR should be based on both the target signature and the sensor or seeker performance. Thus it would not be appropriate to change the radar missile, for example, without making changes in RADMISSERR. The maneuver is described in three segments: a 6 degree per second turn to the right for 15 seconds, followed by a left turn at the same rate for 30 seconds, then another 15 seconds to the right. This results in a sinusoidal weave of period one minute. At 600 fps, 6 degrees per second is approximately a 2G turn.

TABLE 4.4

TARGET INPUTS

```
ALTTGT = 5000.
ASPDIR = 1
BWJAM = 1.E+7
TJAM = 2
VT = 600.
/ target RCS:
RCSTABLE (SQM)
NAZ = 1
NEL = 1
TABLE = 8. , END
END
/ jammer power:
ERPTABLE
NAZ = 5
NEL = 3
ELMIN = -30.DEG
ELSTP =  15.DEG
```

TABLE 4.4 (CONT'D)

TARGET INPUTS

```
TABLE = 10,2,.1,0,0.,
        100,20,1,0,0,
        10,2,.1,0,0,END
END
/ pta lock-on range:
PTATABLE (NMI)
NAZ = 3
NEL = 1
TABLE = 0.,5.,27.,END
END
/ IR missile lock-on range:
IRMSLRANGE (NMI)
NAZ = 3
NEL = 1
TABLE = 0.,1.,5.,END
END
MANEUVER 15. SEC ,0. DEG, 6. DGPS, 0. FPSS, 0. DEG ,
30. SEC ,180. DEG, 6. DGPS, 0. FPSS, 0. DEG ,
15. SEC ,0. DEG, 6. DGPS, 0. FPSS, 0. DEG , END
```

The weapons load and missile inputs are shown in Table 4.5. The radar missile has a semi-active seeker (AAMTYP = 1), a clutter notch with an effective half-width of 98 fps, and requires a S/I ratio of 12:1 for lock-on. There are two missiles of each type(AAMNUM). The radar missile has approximately twice the range, time of flight, and lethal radius as the IR missile. The minimum time without guidance (TDMIN) is important in this example because the target is maneuvering. Both the IR missile and the jammer are aspect-dependent, so as the target turns, the IR missile could lose lock-on, or the jammer could cause loss of track. If the AI radar loses track, so will the missile, since it is semi-active. The radar seeker inputs follow the same format as the AI radar. The missile is always assumed to operate in a high-PRF mode. The flight tables are not used to calculate miss distance, but they are used to determine when missile launches are possible.

TABLE 4.5

MISSILE INPUTS

```
/ AAM seeker
AAMTYP = 1
CMBAAM = 98.
HOJ = 0
SIRAAM = 12.
/ launch criteria:
AAMNUM(RADMIS) = 2, AAMNUM(IRMIS) = 2
ALHE(RADMIS) = 12.DEG, ALHE(IRMIS) = 12.DEG
RLETHL(RADMIS) = 20. FT, RLETHL(IRMIS) = 10. FT
GIMBMX(RADMIS) = 60.DEG, GIMBMX(IRMIS) = 45.DEG
GMAXL(RADMIS) = 7.3G, GMAXL(IRMIS) = 7.3G
RAAMMN(RADMIS) = .7NMI, RAAMMN(IRMIS) = .2NMI
TDMIN(RADMIS) = 3., TDMIN(IRMIS) = 2.
TDMAX(RADMIS) = 61., TDMAX(IRMIS) = 31.
/ missile radar parameters:
RZERO(RADMIS) = 8.3NMI
SNZERO(RADMIS)= 16.3
SIGMA0(RADMIS) = 1SQM
R1(RADMIS) = 7.58NMI
GAMMA1(RADMIS) = .15
VI1(RADMIS) =800.
ALT1(RADMIS) = 20000.
SCV(RADMIS) = 73.DB
```

TABLE 4.5 (CONT'D)

MISSILE INPUTS

```
TAU(RADMIS) = 0.001 MSEC
ALAMB(RADMIS) = 3.CM
AVGPWR(RADMIS) = 170.
TGML(RADMIS)=1700.
RGML(RADMIS)=250.
RGBL(RADMIS)=.25
TBMW(RADMIS)= 4.DEG
RBMW(RADMIS)=14.DEG
FNOISE(RADMIS) = 1.58
ALOSSJ(RADMIS) = .1
SIGMAX(RADMIS) = .00005
GAMMA(RADMIS)=.015
/ radar missile fly-out table:
AAMFTN(RADMIS)=16
TDAAM(RADMIS)= 4.
RAAM(RADMIS) = 0.,4367,10979,18137,24519,30359,35813,40966,45479,
49371,52791,55840,58587,61085,63369,65468
VAAM(RADMIS)=
800.,1403,1907,1676,1517,1404,1323,1219,1040,907,803,
721,653,595,546,503
/ IR missile fly-out table:
AAMFTN(IRMIS)=16
TDAAM(IRMIS)=2.
RAAM(IRMIS)= 0.,2412,6431,10227,13398,16148,18553,20696,22630,
24390,26005,27497,28882,30173,31382,32516
VAAM(IRMIS) = 800.,1692,2097,1732,1455,1283,1136,1018,923,
844,777,719,669,625,586,550
```

Aerodynamic, propulsion, and guidance data for the missiles are given in Tables 4.6 and 4.7. The IR missile has a single burn of 3.3 seconds and uses proportional guidance with a guidance gain of six. The maximum angle of attack is 16 degrees, and the maximum G command is 34. This example uses table inputs to characterize the drag dependency on Mach number and angle of attack. Note that, for this missile, CXCP1C (axial drag during coast) is identical to CXCP1B (axial drag during burn.)

TABLE 4.6

DATA FOR IR MISSILE

```
DTINT(IRMIS)=.2
KGYDE(IRMIS)=1
GNAV1(IRMIS)=6
INCLG(IRMIS)=1
CPTHRST(IRMIS)=3057LB
CPMASSI(IRMIS)=186.5LB
CPMASSF(IRMIS)=146.4LB
CPNEA(IRMIS)=123.SQCM
CPTB(IRMIS)=3.3SEC
TCOB4I(IRMIS)=0
TCOABO(IRMIS)=99999
CPAREA(IRMIS)=200.SQCM
ALFMXCP(IRMIS)=16DEG
ANMAXCP(IRMIS)=34G
CXCP1B (IRMIS) (DEG)
1.25,  0.,.9, 3.,1.1, 6.,1.7, 12.5,4.0, END
1.75,  0.,.9, 3., 1.1, 6.,1.6, 12.,3.7, END
2.00,  0.,.8, 3.,1., 6.,1.5, 12.5,3.5, END
3.00,  0.,.8, 3.5,.9,7.,1.3,14.,3.0, END
4.00,  0.,.7, 3.8,.8,7.5,1.2,15.,2.5, END
5.00,  0.,.7,4.,.8,8.,1.1,16.,2.3, END ,END
```

TABLE 4.6 (CONT'D)

DATA FOR IR MISSILE

```
CXCP1C (IRMIS) (DEG)
1.25,  0.,.9, 3.,1.1, 6.,1.7, 12.5,4.0, END
1.75,  0.,.9, 3., 1.1, 6.,1.6, 12.,3.7, END
2.00,  0.,.8, 3.,1., 6.,1.5, 12.5,3.5, END
3.00,  0.,.8, 3.5,.9,7.,1.3,14.,3.0, END
4.00,  0.,.7, 3.8,.8,7.5,1.2,15.,2.5, END
5.00,  0.,.7,4.,.8,8.,1.1,16.,2.3, END ,END
CNCP1 (IRMIS) (DEG)
1.25,  0.,0., 3.,3.5, 6.,7., 12.5,14., END
1.75, 0.,0., 3.,3.5, 6.,7., 12.,13., END
2.00, 0.,0., 3.,3.0, 6.,6., 12.5,11., END
3.00, 0.,0., 3.5,2., 7.,4.5, 14.,9., END
4.00, 0.,0., 3.8,1.5, 7.5,3.5, 15.,6.5, END
5.00, 0.,0., 4.,1.5, 8.,3., 16.,6. , END, END
```

The radar missile is modeled as two stages to account for the different thrusts during boost and sustain (CPTHRST in Table 4.7). The booster burns for 8 seconds and the sustain stage lasts 18.9 seconds (CPTB). Since there are two stages, all the drag constants are repeated. That is, CXCP1B, CXCP1C, and CNCP1 are identical to CXCP2B, CXCP2C, and CNCP2 respectively. The only real differences between the two stages are the initial and final masses (CPMASSI and CPMASSF), the thrusts (CPTHRST), and the burn times (CPTB).

TABLE 4.7

DATA FOR RADAR MISSILE

```
KGYDE(RADMIS)=1
GNAV1(RADMIS)=6
INCLG(RADMIS)=1
CPMASSI(RADMIS)= 244.9KG,196.9KG
DTINT(RADMIS)=.2,.2
CPTHRST(RADMIS)=14950NEWT,4260NEWT
CPMASSF(RADMIS)=196.9KG,163.1KG
TCOABO(RADMIS)=0,99999
CPNEA(RADMIS)= 209.4SQCM, 209.4SQCM
CPTB(RADMIS)= 8.SEC, 18.9SEC
CPAREA(RADMIS)= 394.SQCM, 394.SQCM
ALFMXCP(RADMIS)= 6.DEG,6.DEG
ANMAXCP(RADMIS)= 34G, 34G
CXCP1B (RADMIS) (DEG)
1.25,  0,.8,1.25,.8,2.7,1.,5.7,1.6,END
1.75,   0,.8,1.2,.8,2.4,1.,4.8,1.6,END
2.00,   0,.7,1.1,.7,2.3,.9,4.6,1.4,END
3.00,  0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
4.00,  0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
5.00,  0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
CXCP1C  (RADMIS) (DEG)
1.25,  0,.8,1.25,.8,2.7,1.,5.7,1.6,END
1.75,   0,.8,1.2,.8,2.4,1.,4.8,1.6,END
2.00,   0,.7,1.1,.7,2.3,.9,4.6,1.4,END
3.00,  0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
4.00,  0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
5.00,  0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
```

TABLE 4.7 (CONT'D)

DATA FOR RADAR MISSILE

```
CNCP1  (RADMIS) (DEG)
1.25,  0,0, 1.25,2.4, 2.75,5, 5.7,10, END
1.75, 0,0, 1.2,2.3, 2.4,4.8, 4.8,10., END
2.00, 0,0, 1.1,1.2, 2.3,4, 4.6,8.5, END
3.00, 0,0, 1.2,1.4, 2.5,2.6, 5,5, END
4.00, 0,0, 1.3,1.25, 2.6,2.25, 5.3,4.5, END
5.00, 0,0, 1.3,1.1, 2.8,2, 5.7,3.9, END, END
CXCP2B  (RADMIS) (DEG)
1.25,  0,.8,1.25,.8,2.7,1.,5.7,1.6,END
1.75,  0,.8,1.2,.8,2.4,1.,4.8,1.6,END
2.00,  0,.7,1.1,.7,2.3,.9,4.6,1.4,END
3.00,  0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
4.00,  0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
5.00,  0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
CXCP2C  (RADMIS) (DEG)
1.25,  0,.8,1.25,.8,2.7,1.,5.7,1.6,END
1.75,  0,.8,1.2,.8,2.4,1.,4.8,1.6,END
2.00,  0,.7,1.1,.7,2.3,.9,4.6,1.4,END
3.00,  0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
4.00,  0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
5.00,  0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
CNCP2  (RADMIS) (DEG)
1.25,  0,0, 1.25,2.4, 2.75,5, 5.7,10, END
1.75, 0,0, 1.2,2.3, 2.4,4.8, 4.8,10., END
2.00, 0,0, 1.1,1.2, 2.3,4, 4.6,8.5, END
3.00, 0,0, 1.2,1.4, 2.5,2.6, 5,5, END
4.00, 0,0, 1.3,1.25, 2.6,2.25, 5.3,4.5, END
5.00, 0,0, 1.3,1.1, 2.8,2, 5.7,3.9, END, END
```

5 ENGAGE II OUTPUT

ENGAGE II can generate several different output files, depending on the options selected by the user. All files have an identical heading, giving the date, time, and run number of the run; and an input summary page. A sample of the output heading and the input summary are included as Fig. 5.1 and Fig. 5.2. These samples, and all those included to illustrate the following output files, have been generated with the input file described in Section 4.

A brief description of each of these output files follows.

5.1 EVENT HISTORY FILE

This file describes the events occurring in each engagement in the run. There is one engagement per page, identified by the Heading Crossing Angle and the initial Offset of the engagement. Then each event is listed, with the following information:

- The Event name.
- The time of the event.
- The AI X and Y coordinates at the time of the event.
- The target X and Y coordinates at the time of the event.
- The location of the AI relative to the target, in X, Y, and Z coordinates, at the time of the event.
- Further comments about the event.

The comments referred to in Item 6 vary with the event type. Table 5.1 lists the various comments and briefly describes them.

This file is generated when the value of user-input IEVHIS is 1. Figure 5.3 illustrates an example of this output.

```
                 PROGRAM ENGAGE  II

      ONE-ON-ONE AIR ENGAGEMENT SIMULATION


            RUN DATE IS   3-APR-84

            RUN TIME IS  19:25:26


             RUN NUMBER IS    20


          GENERAL RESEARCH CORPORATION
            5383 HOLLISTER AVENUE
            POST OFFICE BOX  6770
           SANTA BARBARA, CALIFORNIA
                  93111-0770
```

Figure 5.1. Sample Output Heading

```
                              INPUT SUMMARY

AI:        INITIAL VELOCITY                800.00 FEET/SEC
           INITIAL ALTITUDE               5500.00 FEET
           G LOAD                          209.13 FEET/SEC**2
           VISIBLE RANGE                 30401.50 FEET

TARGET:    INITIAL VELOCITY                600.00 FEET/SEC
           INITIAL ALTITUDE               5000.00 FEET
           JAMMING                      TRACK-BREAK

SENSORS:   PASSIVE TRACK ADJUNCT        AUTONOMOUS

           RADAR                        HIGH AND MEDIUM PRF
             DETECTION                  CUMULATIVE PD
             DETECTION THRESHOLD             0.5000
             ACQUISITION THRESHOLD          21.0000
             TRACK-ON-JAM THRESHOLD         10.0000

WEAPONS:   RADAR MISSILES                  2    LOBL TYPE (SEMI-ACTIVE)
             LOCK-ON THRESHOLD              12.0000
             HOME-ON-JAM THRESHOLD      NONE
             MAXIMUM RANGE                65468.00 FEET

           IR MISSILES                     2
             ASPECT                     REAR
             MAXIMUM RANGE                32516.00 FEET

           GUN RANGE                       1216.06 FEET
```

Figure 5.2. Sample Input Summary

TABLE 5.1

EVENT HISTORY FILE

EVENT DESCRIPTION

EVENT NAME	DESCRIPTION
INITIATION	INITIAL RANGE IS xxx.xx
PTA DETECT	PTA AUTONOMOUS MODE
	PTA RADAR CLUE MODE. NEW TSTEP = xxxx.xx
	TSTEP is the new radar scan time.
DETECTION	SSPD,PDCUM,SIR = xxx.xxxx xxx.xxxx x.xxxExx
	SSPD is the Single-Scan Probability of Detection, PDCUM is the Cumulative Probability of Detection, and SIR is the Signal-to-Interference Ratio at the time of detection.
	TOJ SUCCESS. J/N, TTOJ = xx.xxxx xx.xxxx
	Track-on-Jam detection.
	J/N is the Jammer-to-Noise ratio, and TTOJ is the Track-on-Jam Threshold.
TRACK	SSPD,PDCUM,SIR = xxx.xxxx xxx.xxxx x.xxxExx
	SSPD is the Single-Scan Probability of Detection, PDCUM is the Cumulative Probability of Detection, and SIR is the Signal-to-Interference Ratio at the time of AI radar lock-on.

TABLE 5.1 (CONT'D)

EVENT HISTORY FILE

EVENT DESCRIPTION

EVENT NAME	DESCRIPTION
AAM LAUNCH	LAUNCH HOJ RADAR MISSILE. J/N IS x.xxxExx Radar missile launched in Home-on-Jam launch mode. J/N is the Jammer-to-Noise ratio at the missile seeker. LAUNCH PTA RADAR MISSILE. AIM RANGE IS xxxxx. Radar missile launched in Passive Track Adjunct launch mode. AIM RANGE is the range to the expected impact point. LAUNCH PTA IR MISSILE. AIM RANGE IS xxxxx. IR missile launched in Passive Track Adjunct launch mode. AIM RANGE is the range to the expected impact point. TRACK RADAR MSL LAUNCH. S/I IS x.xxxxExx Radar missile launched in AI radar track launch mode. S/I is the Signal-to-Interference Ratio for the Radar missile seeker at the time of launch. TRACK IR MSL LAUNCH. AIM RANGE IS xxxxx. IR missile launched in AI radar track launch mode. AIM RANGE is the range to the expected impact point.
AAM IMPACT	CA. T = xxx.x SEC, MD = xxxx.x FT, PK = x.xx T is the time of Closest Approach (CA), MD is the Miss Distance at CA, and PK is the Missile Probability of Kill.

TABLE 5.1 (CONT'D)

EVENT HISTORY FILE

EVENT DESCRIPTION

EVENT NAME	DESCRIPTION
AAM ABORT	EXCEEDED MAX GUIDED FLT TIME. TIME = xxxx.x The missile flight time has exceeded the maximum guided flight time. TIME is the time of the abort of the missile flight. EXCEEDED MAX BLIND FLT TIME. TIME = xxxx.x The missile flight has been blinded for longer than the maximum allowed blind flight time. TIME is the time of the abort of the missile flight. LOST ILLUMINATOR AT TIME xxxx.x A semi-actively guided missile requires the target be illuminated by the AI, but the illumination has ceased. TIME is the time of the abort of the missile flight. HIT THE GROUND. TIME = xxxx.x The missile z-coordinate is negative. TIME is the time of the abort of the missile flight.
TRACK LOST	TGT AZ,EL,SIR = xxx.x xx.x DEG, x.xxExx AZ is the Azimuth angle of the target at the AI, EL is the Elevation angle of the target at the AI, and SIR is the Signal-to-Interference Ratio.
GUN POSITION	RANGE, ATA = xxxx.xx x.xxxx RANGE is the range of the AI to the Target when successful gun position is reached, and ATA is the angle of the target off the AI boresight.

TABLE 5.1 (CONT'D)

EVENT HISTORY FILE

EVENT DESCRIPTION

EVENT NAME	DESCRIPTION
END TRACK	SUCCESSFUL GUN POSITION. RNG IS xxxxxx.xx RNG is the range of the AI to the Target at the end-of-track.
	ALL MSLS FIRED, GUN RANGE IS xxxx.xx GUN RANGE is the range of the AI to the Target when gun position and end-of-track are simultaneously reached.
	ALL WEAPONS LAUNCHED. Gun Position notrequested for this engagement.
	LOST TRACK AT xxxx.x COULD NOT REACQUIRE. The AI radar lost track at time given.
	TGT xxxx.x DEG OFF AI. MAX SIR = x.xxxExx The target is beyond 90 degrees off the AI boresight. SIR is the the maximum Signal-to-Interference atio for the engagement.
	TIME EXCEEDED TABORT. xxxx.x xxxx.x The engagement time has exceeded the maximum allowed engagement time, user-input TABORT. TIME and TABORT are displayed.
NO DETECT	TGT xxxx.x DEG OFF AI. MAX SIR = x.xxxExx The target is beyond 90 degrees off the AI boresight. SIR is the the maximum Signal-to-Interference ratio for the engagement.
	TIME EXCEEDED TABORT. xxxx.x xxxx.x The engagement time has exceeded the maximum allowed engagement time, user-input TABORT. TIME and TABORT are displayed.

TABLE 5.1 (CONT'D)

EVENT HISTORY FILE

EVENT DESCRIPTION

EVENT NAME	DESCRIPTION
ONLY PTA	TGT xxxx.x DEG OFF AI. MAX SIR = x.xxxExx The target is beyond 90 degrees off the AI boresight. SIR is the the maximum Signal-to-Interference ratio for the engagement. TIME EXCEEDED TABORT. xxxx.x xxxx.x The engagement time has exceeded the maximum allowed engagement time, user-input TABORT. TIME and TABORT are displayed.
DET NO TRK	TGT xxxx.x DEG OFF AI. MAX SIR = x.xxxExx The target is beyond 90 degrees off the AI boresight. SIR is the the maximum Signal-to-Interference ratio for the engagement. TIME EXCEEDED TABORT. xxxx.x xxxx.x The engagement time has exceeded the maximum allowed engagement time, user-input TABORT. TIME and TABORT are displayed.
TERMINATION	ENGAGEMENT PK IS x.xx PK is the Probability of Kill for the engagement.

NOTE: All values (xx.x) displayed are in program internal units (feet, pounds, seconds, radians) unless otherwise labeled.

RUN NUMBER 20

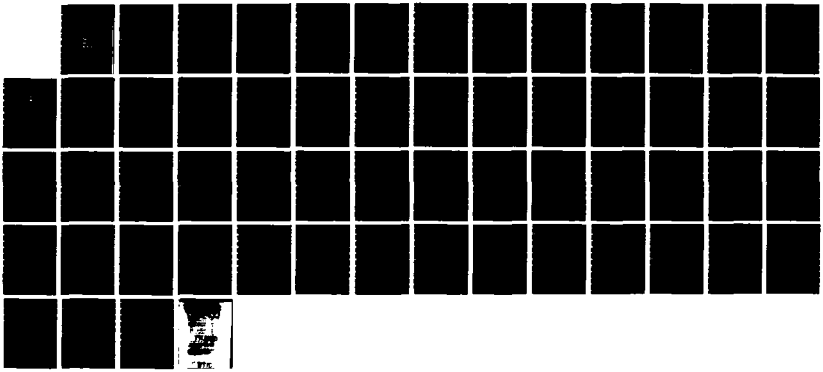
EVENT HISTORY FOR OFFSET NUMBER 2 WITH INITIAL OFFSET = 0.00 FT AND HCA = 90.00 DEG

EVENT TYPE	REL TIME SEC	INTERCEPTOR X KFT	INTERCEPTOR Y KFT	TARGET X KFT	TARGET Y KFT	AI RELATIVE TO TARGET X KFT	AI RELATIVE TO TARGET Y KFT	AI RELATIVE TO TARGET Z KFT	DESCRIPTION...
INITIATION	0.00	118.57	158.09	0.00	0.00	-118.57	-158.09	-0.50	INITIAL RANGE IS 197610.38
DETECTION	5.80	118.57	153.45	3.27	-1.02	-115.30	-154.47	-0.50	SSPD, PDCUM, SIR= 0.1354 0.5587 0.602E+01
TRACK	26.80	118.57	136.65	9.57	-11.14	-108.99	-147.79	-0.50	SSPD, PDCUM, SIR= 0.5831 0.9904 0.250E+02
AAM LAUNCH	108.80	93.39	70.97	40.55	-3.51	-52.83	-74.48	-0.26	TRACK RADAR MSL LAUNCH. S/I IS 0.122E+02
AAM ABORT	170.80	74.90	13.81	64.05	-2.46	-10.85	-16.27	-0.06	EXCEEDED MAX GUIDED FLT TIME TIME 170.8
AAM LAUNCH	175.80	72.50	9.44	66.32	-0.55	-6.19	-9.99	-0.04	TRACK RADAR MSL LAUNCH. S/I IS 0.444E+05
AAM IMPACT	182.80	68.22	4.46	70.41	-0.24	2.19	-4.70	-1.35	CA. T= 182.5 SEC, MD= 0.0 FT, PK= 1.00
AAM LAUNCH	191.80	69.41	-2.20	74.17	-3.85	4.75	-1.65	-2.65	TRACK IR MSL LAUNCH. AIM RANGE IS 7563.
AAM IMPACT	196.80	72.58	-4.18	74.59	-6.80	2.00	-2.62	-0.98	CA. T= 195.9 SEC, MD= 0.1 FT, PK= 1.00
AAM LAUNCH	201.80	74.59	-7.44	75.88	-9.47	1.29	-2.03	-0.30	TRACK IR MSL LAUNCH. AIM RANGE IS 4197.
AAM IMPACT	204.80	75.83	-9.29	77.25	-10.63	1.42	-1.34	-0.07	CA. T= 204.7 SEC, MD= 0.3 FT, PK= 1.00
GUN POSITION	205.80	76.32	-9.84	77.77	-10.91	1.45	-1.07	-0.03	RANGE, ATA = 1806.33 0.1478
END TRACK	205.80	76.32	-9.84	77.77	-10.91	1.45	-1.07	-0.03	ALL MSLS FIRED, GUN RANGE IS 1806.33
TERMINATION	205.80	76.32	-9.84	77.77	-10.91	1.45	-1.07	-0.03	ENGAGEMENT PK IS 1.00

Figure 5.3. Sample Events History Output

AD-A144 119 ENGAGE II - USER'S MANUAL(U) GENERAL RESEARCH CORP SANTA BARBARA CA J BALTES ET AL. 31 MAY 84 GRC-CR-2-1091 F33615-81-C-0108 2/2

UNCLASSIFIED F/G 5/9 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

5.2 EVENT SUMMARY FILE

This output file (Fig. 5.4) summarizes all occurrences of several event types for those engagements flown at a single Heading Crossing Angle (HCA). The top line of the output identifies the HCA. The selected AI event types are: detection (all types), track, and the end-of-engagement events. For each event type, the engagement is identified by index, and the time and relative location of the AI to the target. A similar summary is generated for the two missile events AAM launch and AAM impact. These event summaries are repeated for each HCA in the run. The user selects this output by setting the input IEVSUM to 1.

5.3 FLIGHT SUMMARY FILE

This file contains two short summaries over all engagements in the run. The file is generated when the input variable IFLSUM is 1. These summaries are illustrated in Figs. 5.5 and 5.6.

5.3.1 Summary By Engagement

Each engagement is listed on a single line, with the following information:

- HCA -- Heading Crossing Angle
- OFFSET -- Initial Offset distance
- RESULTS -- a description of the AI detection
  - FAILURE -- No detection by AI
  - PTA DET -- Detection by PTA only
  - RADAR DET -- Detection but not lock-on by AI radar
  - RADAR TRK -- AI radar lock-on achieved.

For Radar Missiles:

- HOJ -- Number of radar Missiles Launched in Home-On-Jam launch mode.
- PTA -- Number of radar missiles launched in PTA launch mode.

RUN NUMBER 20
DETECTION AND TRACK EVENT SUMMARY FOR HEADING CROSSING ANGLE OF 90.00 DEG

FLY	--- DETECTION---		--- BEGIN TRACK ---			--- END OF TRACK ---			--- NO DETECTION ---			--DETECTION NO TRACK--		
BY	REL X KFT	REL Y KFT	TIME SEC	REL X KFT	REL Y KFT	TIME SEC	REL X KFT	REL Y KFT	TIME SEC	REL X KFT	REL Y KFT	TIME SEC	REL X KFT	REL Y KFT
1	-110.30	-158.47	26.8	-103.99	-151.79	206.8	1.55	-0.90						
2	-115.30	-154.47	26.8	-108.99	-147.79	205.8	1.45	-1.07						
3	-120.30	-154.47	26.8	-113.99	-147.79	206.8	1.52	-0.88						

RUN NUMBER 20
AAM LAUNCH AND IMPACT EVENT SUMMARY FOR HEADING CROSSING ANGLE OF 90.00 DEG

FLY	--- AAM LAUNCH 1 ---			--- AAM IMPACT 1 ---			--- AAM LAUNCH 2 ---			--- AAM IMPACT 2 ---		
BY	TIME SEC	REL X KFT	REL Y KFT	TIME SEC	REL X KFT	REL Y KFT	TIME SEC	REL X KFT	REL Y KFT	TIME SEC	REL X KFT	REL Y KFT
1	109.8	-49.77	-75.78	171.8	-10.20	-16.74	176.8	-5.81	-10.48	184.8	3.07	-4.70
2	108.8	-52.83	-74.48	170.8	-10.85	-16.27	175.8	-6.19	-9.99	182.8	2.19	-4.70
3	110.8	-54.08	-72.82	172.8	-10.61	-15.19	177.8	-5.87	-9.28	184.8	2.15	-4.61

Figure 5.4. Sample Event Summary Output: Detection and Track Summary, Launch and Impact Summary

RUN NUMBER 20
FLIGHT SUMMARY

HCA (DEG)	OFFSET (FT)	RESULTS	MISSILE LAUNCHES: RADAR MISSILES HOJ	RADAR MISSILES PTA	RADAR MISSILES TRK	RADAR MISSILES AVG MD (FT)	IR MISSILES PTA	IR MISSILES TRK	IR MISSILES AVG MD (FT)	TOTAL	PK	SUCCESSFUL GUN POSITION
180.0	-5000.0	RADAR TRK	0	0	2	0.9	0	0	0.0	2	1.00	YES
180.0	0.0	RADAR TRK	0	0	2	0.3	0	2	0.1	4	1.00	YES
180.0	5000.0	RADAR TRK	0	0	2	283.1	0	0	0.0	2	1.00	YES
145.0	-5000.0	RADAR TRK	0	0	2	114.8	0	2	0.1	4	1.00	YES
145.0	0.0	RADAR TRK	0	0	2	85.7	0	2	0.1	4	1.00	YES
145.0	5000.0	RADAR TRK	0	0	2	76.2	0	2	0.3	4	1.00	YES
90.0	-5000.0	RADAR TRK	0	0	2	0.0	0	2	0.8	4	1.00	YES
90.0	0.0	RADAR TRK	0	0	2	0.0	0	2	0.2	4	1.00	YES
90.0	5000.0	RADAR TRK	0	0	2	0.1	0	2	0.3	4	1.00	YES
45.0	-5000.0	RADAR TRK	0	0	2	0.4	0	0	0.0	2	1.00	YES
45.0	0.0	RADAR TRK	0	0	2	0.1	0	0	0.0	2	1.00	YES
45.0	5000.0	RADAR TRK	0	0	2	0.2	0	0	0.0	2	1.00	YES
0.0	-5000.0	RADAR TRK	0	0	2	2832.0	0	2	0.2	4	1.00	YES
0.0	0.0	RADAR TRK	0	0	2	0.1	0	2	0.3	4	1.00	YES
0.0	5000.0	RADAR TRK	0	0	2	0.1	0	2	0.4	4	1.00	YES

Figure 5.5. Sample Flight Summary Output: Summary by Engagement

```
                 RUN NUMBER  20
                 FLIGHT   SUMMARY

       NUMBER OF HEADING CROSSING ANGLES  =  5
         NUMBER OF OFFSETS FOR EACH HCA  =  3

            TOTAL NUMBER OF FLIGHTS  = 15

NUMBER OF FLIGHTS WITH:

    SUCCESSFUL TARGET DETECTION BY RADAR OR PTA   15
      TARGET DETECTION BY PTA, NOT BY RADAR           0
      TARGET DETECTION, NO ACQUISITION, BY RADAR      0
      TARGET TRACK BY RADAR                          15

    AT LEAST ONE MISSILE LAUNCH                   15
      AT LEAST ONE HOJ RADAR MISSILE LAUNCH           0
      AT LEAST ONE PTA RADAR MISSILE LAUNCH           0
      AT LEAST ONE TRACK RADAR MISSILE LAUNCH        15
      AT LEAST ONE PTA IR MISSILE LAUNCH              0
      AT LEAST ONE TRACK IR MISSILE LAUNCH           10

    SUCCESSFUL GUN POSITION REACHED               15

            CUMULATIVE PD   =   1.0000
            CUMULATIVE PDC  =   1.0000
```

Figure 5.6. Sample Flight Summary Output: Cumulative Summary

- TRK — Number of radar missiles launched in radar track launch mode.
- AVG MD — Average miss distance for all radar missiles which did not abort in flight.

For IR Missiles:

- PTA — Number of IR missiles launched in PTA launch mode.
- TRK — Number of IR missiles launched in radar track launch mode.
- AVG MD — Average miss distance for all IR missiles which did not abort in flight.
- TOTAL — Total number of missiles (both radar and IR) launched.
- PK — The engagement Probability of Kill, PK
- GUN POSITION — Successful gun position indicator flag

  YES — Position reached

  NO — Position not reached

5.3.2 Cumulative Summary

This summary accumulates the number of engagement flights which meet several specific conditions, and produces the average Probability of Detection, PD, and the average Probability of Detection and Conversion, PDC, for all engagement flights in the run. These probabilities are defined as:

$$PD = NDET / NTOT$$

where NDET is the number of flights with successful detection by the AI radar or PTA, and NTOT is the total number of engagements; and

$$PDC = NLNCH / NTOT$$

where NLNCH is the number of flights with at least one missile launch.

5.4 FLIGHT PLOT FILE

This file contains the state of the AI, target, and each missile launched in the engagement at each time step in the engagement. The file can then be used by a post-processor to generate trajectory plots. The state is an array of 10 elements containing:

- Time of the state
- X Position at this time
- Y Position at this time
- Z Position at this time
- X-Dot (X-component of velocity) at this time
- Y-Dot (Y-component of velocity) at this time
- Z-Dot (Z-component of velocity) at this time
- X-Double-Dot (X-component of acceleration) at this time
- Y-Double-Dot (Y-component of acceleration) at this time
- Z-Double-Dot (Z-component of acceleration) at this time

The missile is identified by missile type (Radar or IR) and the number of the missile (of this type).

The input variable IFLPLT is used to activate this output. Figure 5.7 provides a sample of this output.

5.5 DIAGNOSTICS FILE

Diagnostics can be generated by setting an input variable, KOUT. This output is used for debugging and for tracing logic flow, time step by time step. The resulting output file can be voluminous; it should be used only for a single engagement. Some knowledge of the code is required to decipher it since it references values by internal program variable names. Each output line contains the routine name, dashes, the program variable names, and their values. There are several levels of diagnostics available -- each adding to the last.

AI	0	0	185.6	70611.12	20675.67	5048.31	390.26	-920.70	-2.34	-12.67	-5.37	0.12
TARGET	0	0	185.6	71925.57	-957.28	5000.05	499.75	-332.03	0.00	-34.76	-58.33	0.00
MSL	1	1	185.6	72085.48	1194.73	5005.08	445.41	-1109.52	-2.01	-26.68	36.22	0.31
AI	0	0	186.6	70792.88	19751.43	5066.02	373.24	-927.73	-2.24	-17.08	-6.87	0.11
TARGET	0	0	186.6	72407.03	-1314.85	5000.05	462.30	-382.45	0.00	-40.04	-48.41	0.00
MSL	1	1	186.6	72515.89	102.14	5003.23	413.83	-1076.79	-1.71	-36.05	29.57	0.30
AI	0	0	187.6	71355.44	18019.49	5063.83	351.83	-936.06	-2.14	-21.51	-8.08	0.10
TARGET	0	0	187.6	72848.49	-1720.79	5000.05	419.80	-428.68	0.00	-44.89	-43.96	0.00
MSL	1	1	187.6	72910.26	-960.79	5001.65	376.34	-1049.13	-1.95	7.72	38.93	-8.77
AI	0	0	188.6	71694.52	17878.76	5061.73	326.28	-945.27	-2.05	-23.67	-8.86	0.09
TARGET	0	0	188.6	73245.09	-2170.65	5000.05	372.69	-470.21	0.00	-49.25	-39.03	0.00
MSL	1	1	188.6	73260.20	-1798.77	5000.25	326.42	-1023.06	-5.13	-21.04	46.85	-41.14
AI	0	0	189.6	72006.15	16728.61	5059.72	296.94	-934.90	-1.98	-29.49	-9.17	0.07
TARGET	0	0	189.6	73592.51	-2659.50	5000.05	321.49	-506.60	0.00	-53.05	-33.67	0.00
MSL	1	1	188.9	73361.35	-2322.40	5000.08	295.74	-1009.40	-1.20	-343.62	8.28	-238.31
AI	0	0	190.6	72286.76	15768.83	5057.77	264.22	-964.46	-1.91	-32.87	-9.01	0.06
TARGET	0	0	190.6	73086.91	-3181.99	5000.05	266.79	-537.43	0.00	-56.29	-27.94	0.00
AI	0	0	191.6	72533.18	14799.73	5055.88	228.56	-973.53	-1.86	-35.82	-8.41	0.05
TARGET	0	0	191.6	74125.09	-3732.37	5000.05	209.14	-562.37	0.00	-58.89	-21.90	0.00
AI	0	0	192.6	72742.68	14021.99	5054.05	190.39	-981.71	-1.82	-38.32	-7.43	0.04
TARGET	0	0	192.6	74304.44	-4304.67	5000.05	149.21	-581.15	0.00	-60.85	-15.63	0.00
AI	0	0	193.6	72913.02	13036.60	5052.25	150.23	-988.65	-1.78	-40.30	-6.12	0.04
TARGET	0	0	193.6	74422.98	-4892.56	5000.05	87.65	-593.56	0.00	-62.16	-9.18	0.00
AI	0	0	194.6	73042.45	12045.16	5050.48	108.59	-994.08	-1.75	-41.74	-4.56	0.03
TARGET	0	0	194.6	74479.42	-5489.63	5000.05	25.13	-599.47	0.00	-62.78	-2.63	0.00
MSL	1	2	194.6	73042.45	12045.16	5050.48	108.59	-994.08	-1.75	-41.74	-4.56	0.03
AI	0	0	195.6	73129.74	11049.06	5048.73	65.97	-997.82	-1.74	-42.70	-2.82	0.02
TARGET	0	0	195.6	74495.75	-6089.32	5000.05	37.68	-598.81	0.00	62.70	3.94	0.00
MSL	1	2	195.6	73148.67	10972.66	5048.62	105.04	-1150.30	-2.09	4.50	-153.86	-0.43
AI	0	0	196.6	73197.84	10051.38	5047.24	70.24	-997.53	-1.26	4.27	0.30	0.47
TARGET	0	0	196.6	74564.69	-6685.07	5000.05	100.07	-591.60	0.00	61.95	10.48	0.00
MSL	1	2	196.6	73260.17	9746.42	5046.35	122.24	-1301.12	-2.41	30.05	-147.55	-0.23
AI	0	0	197.6	73297.36	9056.49	5045.97	128.74	-991.68	-1.26	58.31	7.57	0.01
TARGET	0	0	197.6	74695.52	-7270.35	5000.05	161.35	-577.90	0.00	60.52	16.90	0.00
MSL	1	2	197.6	73401.59	8372.78	5043.84	164.60	-1444.85	-2.61	54.02	-139.62	-0.19
AI	0	0	198.6	73455.44	8069.21	5044.71	187.32	-982.30	-1.26	58.29	11.12	-0.01
TARGET	0	0	198.6	74886.80	-7838.75	5000.05	220.87	-557.86	0.00	58.42	23.13	0.00
MSL	1	2	198.6	73596.56	6859.66	5041.13	228.42	-1579.81	-2.82	72.49	-130.10	-0.25
AI	0	0	199.6	73670.39	7097.87	5043.45	242.26	-959.88	-1.27	53.98	23.95	0.00
TARGET	0	0	199.6	75136.46	-8384.04	5000.05	277.98	-531.72	0.00	55.67	29.11	0.00
MSL	1	2	199.6	73863.41	5216.50	5038.17	307.06	-1704.79	-3.16	83.71	-119.78	-0.32
AI	0	0	200.6	73940.27	6145.52	5042.17	297.33	-944.28	-1.29	54.60	17.19	-0.02
TARGET	0	0	200.6	75441.74	-8700.25	5000.05	332.03	-499.75	0.00	52.34	34.77	0.00
MSL	1	2	200.6	74213.27	3453.53	5034.84	393.32	-1819.44	-3.52	87.70	-109.60	-0.41

Figure 5.7. Sample Flight Path Data Output

KOUT	Diagnostics:
0	No diagnostics generated
1	Minimal diagnostics at Event occurrences.
2	Above plus AI and Target states and event failures.
3	Above plus Missile states.

In addition, this output file is used for the hard-copy option available to the user when running the program. This option copies all terminal input and output activity to a file. This is especially useful when the user is working at a terminal screen and would like a printout of the changes made during program execution. The first terminal input requested by the program sets the hard-copy option. A sample of the output generated by this hard-copy option is provided in Fig 5.8.

```
***UNIT   1 INPUT - / irmissile lock-on range:
***UNIT   1 INPUT - IRMSLRANGE (NMI)
***UNIT   1 INPUT - NAZ = 3
***UNIT   1 INPUT - NEL = 1
***UNIT   1 INPUT - TABLE = 0.,1.,5.,END
***UNIT   1 INPUT - END
***UNIT   1 INPUT -
***UNIT   1 INPUT - MANEUVER
***UNIT   1 INPUT - 15.  SEC ,0.  DEG, 6.  DGPS, 0.  FPSS, 0.  DEG ,
***UNIT   1 INPUT - 30.  SEC ,180.  DEG, 6.  DGPS, 0.  FPSS, 0.  DEG ,
***UNIT   1 INPUT - 15.  SEC ,0.  DEG, 6.  DGPS, 0.  FPSS, 0.  DEG , END
***UNIT   1 INPUT - END
TERMINAL INPUT-- TYPE 'END' WHEN COMPLETED
?
/  any additions or changes can be made here during program run
?
END
ANOTHER CASE (Y/N)?
?
Y
TERMINAL INPUT-- TYPE 'END' WHEN COMPLETED
?
/  Read another input file
?
FILE = 21
READ ANOTHER INPUT FILE ON UNIT
21
READ FROM NEW UNIT
***UNIT  21 INPUT - /    ENGAGE II secondary file
***UNIT  21 INPUT - /      This file contains additional data for an ENGAGE II run.
***UNIT  21 INPUT - /
***UNIT  21 INPUT - IDRUN = 200
***UNIT  21 INPUT - /  Run a single case with diagnostics.
***UNIT  21 INPUT - KOUT = 1
***UNIT  21 INPUT - NHCA = 1
***UNIT  21 INPUT - HCA(1) = 45.  DEG
***UNIT  21 INPUT - NOFF = 1
***UNIT  21 INPUT - OFF(1) = 5000.  FT
***UNIT  21 INPUT - /
***UNIT  21 INPUT - /   End of secondary file
***UNIT  21 INPUT - END
TERMINAL INPUT--- TYPE 'END' WHEN COMPLETED
?
/  No more terminal inputs
?
END
```

Primary Input File - Unit 1 (lines from "***UNIT 1 INPUT - / irmissile lock-on range:" to "***UNIT 1 INPUT - END")

Terminal Input (lines from "?" to "21")

Secondary Input File - Unit 21 (lines from "***UNIT 21 INPUT - / ENGAGE II secondary file" to "***UNIT 21 INPUT - END")

Terminal Input (lines from "?" to "END")

Figure 5.8. Sample Hard-Copy Option Output

APPENDIX A

RADAR DETECTION MODELS

Airborne radars can be classified by their ability to distinguish target return signals from clutter (energy reflected from the ground). The techniques employed to achieve this utilize the range and velocity measuring capabilities of radar. Unfortunately, both range and velocity cannot be measured simultaneously with the same degree of accuracy. To a radar, time is the measure of range and frequency is the measure of velocity. Since time and frequency have an inverse relationship, any improvement in range measurement results in a reduction in the ability to measure velocity on a single pulse. For this reason, all airborne radars use information obtained by a long sequence of pulses. The rate at which these pulses occur is called the PRF (pulse repetition frequency). The PRF determines the upper limits on the range and velocity which can be measured unambiguously:

$$\text{Unambiguous Range:} \quad R_u = \frac{c}{2 \cdot PRF} \tag{A.1}$$

where c = speed of light

$$\text{Unambiguous Velocity:} \quad V_u = \frac{\lambda \cdot PRF}{2} \tag{A.2}$$

where λ = wavelength . If the expected target ranges exceed R_u , a radar is said to be ambiguous in range, and similarly for velocity. AI radars can then be classified as:

- Low PRF--Unambiguous in range but ambiguous in velocity.
- High PRF—Ambiguous in range, but unambiguous in velocity.
- Medium PRF--Ambiguous in both range and velocity.

Since we are concerned here with the ability to distinguish targets from clutter, it is often more important to classify radars by clutter ambiguities, rather than just by target ambiguities.

A.1 CLUTTER IN LOW-PRF RADARS

A low-PRF radar, being unambiguous in range, will be able to "range-gate out" all clutter except that which occurs within the same range gate as the target. Thus, the clutter that competes with the target is that within the ring shown in Fig. A.1. For a radar with a constant sidelobe gain, G_{SL}, the clutter return, C, is proportional

$$C = K_L \cdot \frac{G_{SL}^2 \cdot H \cdot \pi c \tau \cdot \gamma_c}{R^4} \qquad (A.\_$$

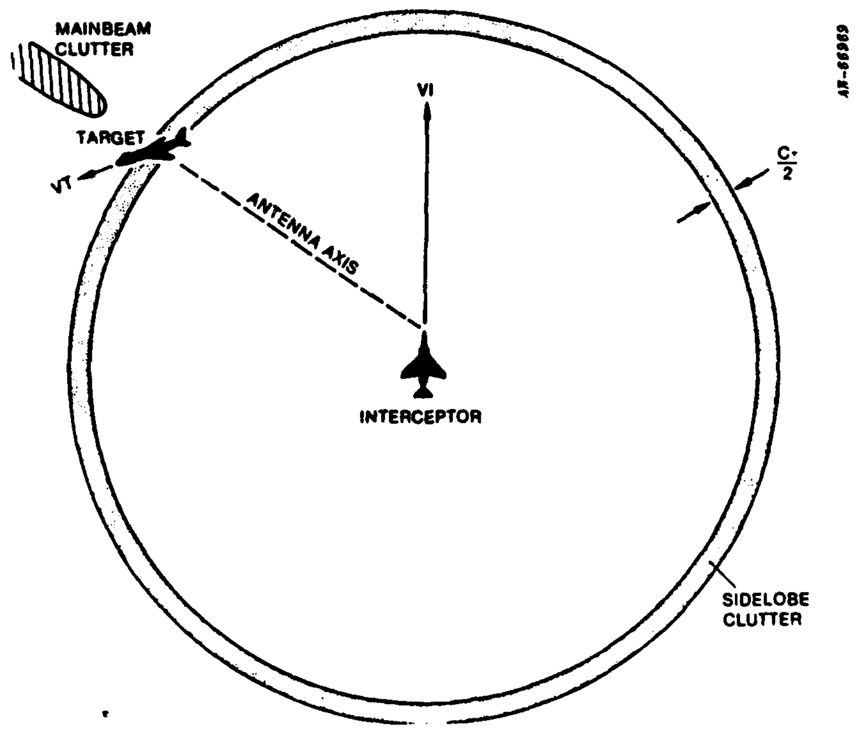


Figure A.1. Low-PRF Clutter Sources

where τ = pulsewidth
γ_c = clutter backscatter coefficient
H = altitude of radar
K_L = constant
R = the range to the target

and the range gate is $c\tau/2$.

We're assuming here that the RCS of the clutter behaves as:

$$\sigma_c = \gamma_c \sin\theta$$

where θ is the grazing angle. If the mainbeam touches the ground, G_{SL} is replaced with G_{ML}, and the clutter return becomes enormous. This accounts for the ineffectiveness of low-PRF radars in "look-down" situations. If, in addition to range-gating, Doppler filtering is used, an additional factor appears in Eq. A.1 to account for the fact that some of the clutter in the ring of Fig. A.1 will not appear at the same (ambiguous) velocity as the target. Typically, this clutter improvement factor is on the order of 2 to 5, and cannot overcome the mainbeam clutter, if present.

A.2 CLUTTER IN HIGH-PRF RADARS

Since high-PRF radars are ambiguous in range, clutter returns from a large number of range rings (Fig. A.2) will appear at the same time as the target. However, only that clutter with Doppler return within a bandwidth (B) of the target's Doppler will compete with the target signal. The total in-band clutter is the sum of all returns from the areas (A_i) of intersecting range rings and the isodop strip (so called because it is bounded by curves of constant Doppler return). This is obviously a very complicated function, but can be approximated by:

$$C = \frac{K_h G_{SL} \gamma_c}{H^2 \cdot V_i} \tag{A.4}$$

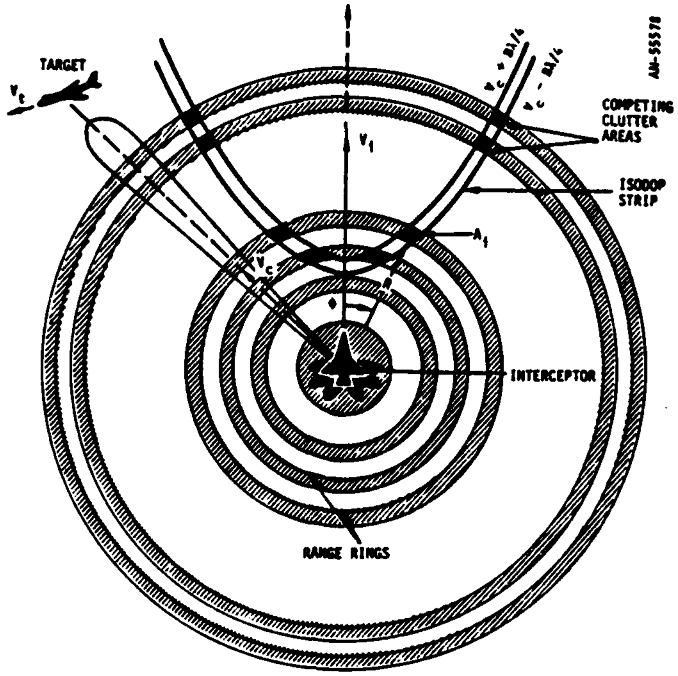


Figure A.2. High-PRF Clutter Sources

---

where V_i = velocity of the interceptor

The constant K_h accounts for the clutter rejection of the Doppler filtering. Note that there is no range dependence here, since the clutter does not all appear at the same range as the target. Mainbeam clutter becomes a problem if the isodop intersects the area on the ground that the mainbeam illuminates. If the closing velocity is greater than the interceptor velocity, the isodop strip is beyond all clutter, since the clutter spectrum is restricted to $\pm V_i$.

Another feature of high-PRF radar is that there is almost always some return from directly below the interceptor, due to the large number of range ambiguities. This return has Doppler velocities near zero, and is very strong, due to the specular reflectivity of the ground at near 90° incidence. For this reason, all high-PRF radars blank out the near-zero Doppler returns, as well as those near the mainbeam clutter return.

A.3 CLUTTER IN MEDIUM-PRF RADARS

The picture for medium-PRF radars (Fig. A.3) is complicated by ambiguities in both range and velocity. It is even more complicated when consideration is given to the several different PRFs that are used in a single scan across the target. This means that the ambiguous range rings and isodop intersections will "move around," effectively washing out any dependence on range, altitude, or velocity. Thus, we model clutter as:

$$C = K_M \cdot G_{SL} \cdot \gamma_c \qquad (A.5)$$

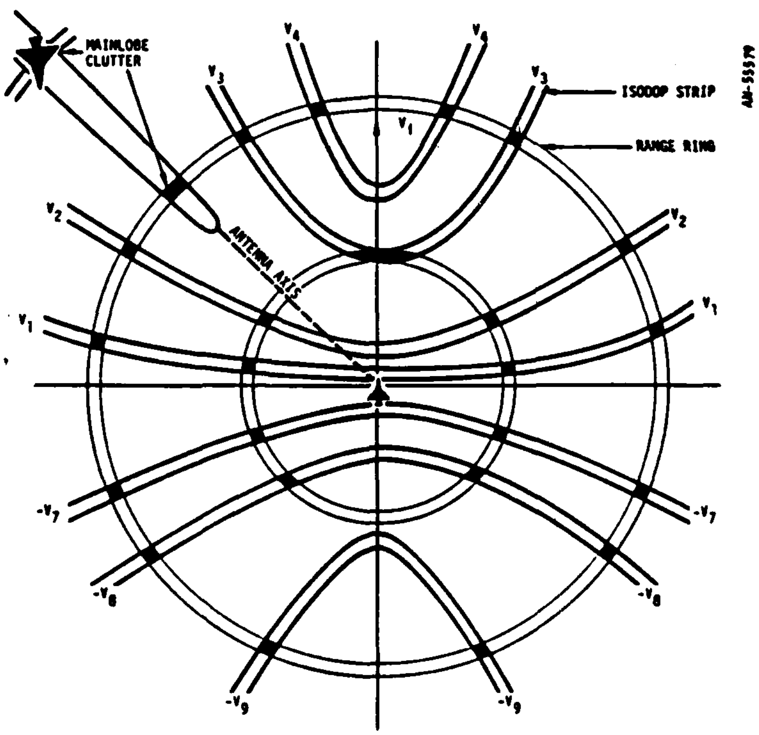


Figure A.3. Clutter Sources for Medium-PRF Radars

The constant K_M here includes both clutter rejection and the averaging effect of multiple PRFs.

Just as with the high-PRF radar, if the mainbeam clutter appears at the same Doppler velocity as the target, G_{SL} is replaced with G_{ML}, and the signal-to-clutter ratio becomes very small. In addition, it is possible for the mainbeam clutter to appear in an ambiguous Doppler bin that matches the target. This is one of the reasons that medium-PRF radars use several PRFs; to assure that some PRFs will be able to resolve all targets except those whose (unambiguous) velocities are within the mainbeam clutter. It is also possible for medium-PRF radars to reject mainbeam clutter through range gating. This happens only if the mainlobe clutter patch is shorter than the unambiguous range (for example, in a very steep look-down). In practice, the mainlobe clutter filters are blanked in all range gates, so real radars cannot take advantage of this possibility.

A.4 SCALING EQUATIONS

We turn our attention now to the equations used in the simulation and the data required to use them. The most common method used to specify radar performance is the range at which a specified cumulative detection probability (usually 0.5 or 0.85) is achieved for a reference RCS. Cumulative detection probability is given by:

$$P_{CUM} = 1 - \prod_i [1 - P_{DSS}(R_i)] \tag{A.6}$$

where P_{DSS} = single scan probability of detection , and the product is taken over all scans across the target as range closes.

For a Swerling I model of target RCS fluctuation:[1]

[1] Harold I. Jacobson, "Simple Formula for Radar Detection Probability on Swerling I Targets," IEEE Transactions on Aerospace and Electronic Systems, March 1981, p. 304.

$$P_{DSS} = P_{fa}^{\frac{1}{1 + S/I}} \qquad (A.7)$$

where $\quad P_{fa}$ = probability of false alarm

and $\quad S/I$ = signal-to-interference power ratio

Since P_{CUM} depends on how rapidly the range closes, it is not easy to scale to conditions different from those under which it was derived.

It is more useful to specify a reference triplet of range, signal-to-noise ratio and RCS (which we'll call R_o, $(S/N)_o$, and σ_o).

To understand why this is a useful approach, consider the following form of the radar range equation:

$$R^4 = \frac{P_T G^2 \lambda^2 \sigma L_T}{(4\pi)^3 k T_s F B_N \left(\frac{S}{N}\right)} \qquad (A.8)$$

The only factor that changes with range and RCS is (S/N). Using our reference values, we can write:

$$R_o^4 = \frac{K_o \sigma_o}{\left(\frac{S}{N}\right)_o} \qquad (A.9)$$

where we have lumped all constants into K_o. At any other range and RCS:

$$R^4 = \frac{K_o \sigma}{\frac{S}{N}} = \frac{R_o^4}{\sigma_o} \cdot \left(\frac{S}{N}\right)_o \cdot \frac{\sigma}{\left(\frac{S}{N}\right)} \qquad (A.10)$$

So if we know any two values, we can solve for the other. For example:

$$\frac{S}{N} = \left(\frac{S}{N}\right)_o \cdot \left(\frac{R_o}{R}\right)^4 \cdot \frac{\sigma}{\sigma_o} \tag{A.11}$$

If clutter is present, we are interested in determining the signal-to-interference ratio:

$$\frac{S}{I} = \frac{S}{N + C} \tag{A.12}$$

As we have seen, determining the actual clutter power can be quite complicated, so we once again resort to scaling. Assume we have a range R_1 , at which our reference target (σ_o) gives a S/I ratio equal to $(S/N)_o$, but with clutter present. Then,

$$\left(\frac{S}{N}\right)_o = \frac{S}{I} = \frac{S}{N + C} = \frac{S/N}{1 + C/N} \tag{A.13}$$

But S/N at R_1 is given by

$$\frac{S}{N} = \left(\frac{S}{N}\right)_o \cdot \left(\frac{R_o}{R_1}\right)^4 \cdot \frac{\sigma_o}{\sigma_o} \tag{A.14}$$

So we can solve for C/N :

$$\frac{C}{N}_1 = \left(\frac{R_o}{R_1}\right)^4 - 1 \tag{A.15}$$

We require $R_1 < R_o$, which means the radar cannot perform better with clutter present than without. We can scale using:

$$\frac{C}{N} = \left(\frac{C}{N}\right)_1 \cdot \frac{\gamma}{\gamma_1} \cdot \frac{H}{H_1} \cdot \left(\frac{R_1}{R}\right)^4 \qquad \text{for low PRF} \qquad (A.16)$$

$$\frac{C}{N} = \left(\frac{C}{N}\right)_1 \cdot \frac{\gamma}{\gamma_1} \qquad \text{for medium PRF} \qquad (A.17)$$

$$\frac{C}{N} = \left(\frac{C}{N}\right)_1 \cdot \frac{\gamma}{\gamma_1} \cdot \left(\frac{H_1}{H}\right)^2 \cdot \frac{V_1}{V} \qquad \text{for high PRF} \qquad (A.18)$$

The subscripted variables refer to the conditions for which R_1 was derived.

We can now write complete expressions for the signal-to-interference ratios:

$$\frac{S}{I} = \frac{\left(\frac{S}{N}\right)_o \cdot \left(\frac{R_o}{R}\right)^4 \cdot \frac{\sigma}{\sigma_o}}{1 + \left[\left(\frac{R_o}{R_1}\right)^4 - 1\right] \cdot \frac{\gamma}{\gamma_1} \cdot \frac{H}{H_1} \cdot \left(\frac{R_1}{R}\right)^4} \qquad \text{for low PRF} \qquad (A.19)$$

$$\frac{S}{I} = \frac{\left(\frac{S}{N}\right)_o \cdot \left(\frac{R_o}{R}\right)^4 \cdot \frac{\sigma}{\sigma_o}}{1 + \left[\left(\frac{R_o}{R_1}\right)^4 - 1\right] \frac{\gamma}{\gamma_1}} \qquad \text{for medium PRF} \qquad (A.20)$$

and

$$\frac{S}{I} = \frac{\left(\frac{S}{N}\right)_o \cdot \left(\frac{R_o}{R}\right)^4 \cdot \frac{\sigma}{\sigma_o}}{1 + \left[\left(\frac{R_o}{R_1}\right)^4 - 1\right] \frac{\gamma}{\gamma_1} \cdot \left(\frac{H_1}{H}\right)^2 \cdot \frac{V_1}{V}} \qquad \text{for high PRF} \qquad (A.21)$$

These equations represent the average, integrated signal-to-interference ratios. They assume constant sidelobe levels and uniform clutter backscatter.

In situations where mainlobe clutter (MLC) is present, the above scaling rules cannot be used. The MLC return can often be strong enough to saturate the receiver. For this reason, we need the actual clutter power, not just a ratio.

Farrell and Taylor have computed the clutter signal return from a Gaussian-shaped mainlobe.[1] They give:

$$C_{ML} = \frac{PG^2\lambda^2\theta^2 D\gamma \sin^2 \theta}{8(4)^3\pi^2 H^2 \log_e 2} \qquad (A.22)$$

This equation gives the mainlobe power entering the radar antenna, after integration over the signal bandwidth ($1/\tau$ hertz). It is a time averaged power as if to assume that MLC is uniformly distributed over all range gates. Loss terms have been omitted.

This clutter can have three detrimental effects:

- It could mask the target in either range or velocity (as previously discussed for each PRF type).
- Even if it is not in the same Doppler bin as the target, it could "feed through" the skirts of the Doppler filters.
- It could saturate the receiver.

Condition (1) can be handled by setting the S/I ratio to 0. For condition (2), we must add that portion of the MLC that passes the Doppler

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[1] J.L. Farrell and R.L. Taylor, "Doppler Radar Clutter," IEEE Transactions on Aerospace and Navigational Electronics, September 1964, p. 162. We have replaced the σ^o backscatter coefficient by $\gamma \sin \theta$.

filter skirts to the noise and in-band clutter. This clutter feed-through will be modeled by multiplying the mainlobe clutter power (C_{ML}) by a clutter improvement factor (I) given by:

$$I \approx \frac{S}{N}_o \cdot SCV \tag{A.23}$$

where subclutter visibility, SCV, accounts for the filter rejection and $(S/N)_o$ approximates the integration gain of signal over clutter. We're assuming the clutter spectrum is similar to noise.

Saturation (condition 3) could be handled by assuming the receiver to be inoperative above the maximum signal level (S_{MAX}). Typically, however, S_{MAX} is the maximum signal strength for linear response. At signal levels above S_{MAX}, the response is compressed and distorted, but not cut off. We will model this effect by multiplying the signal-to-noise ratio by a clutter compression factor:

$$CF = \frac{S_{MAX}}{C_{ML}} \tag{A.24}$$

whenever $C_{ML} > S_{MAX}$.

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whenever $C_{ML} > S_{MAX}$.

APPENDIX B

JAMMING

Three types of jamming are modeled by ENGAGE II:

- Noise jamming, which is assumed to be continuous in time (CW).
- Track break jamming, a responsive technique that denies acquisition.
- Deceptive countermeasures (DECM), which cause errors in range or angle measurement.

All three types of jamming are characterized by the effective radiated power (ERP) and bandwidth (BWJ). Since ERP includes the jammer's antenna gain, it is input as a function of the aspect angles (azimuth and elevation) of the target. BWJ is assumed to be greater than the AI radar bandwidth. Since ENGAGE II is a one-on-one model, all jamming is considered to be in the mainlobe.

The jammer's effects on the radar receiver are dependent on the J/N power ratio:

$$\frac{J}{N} = \frac{ERP}{BWJ} \cdot \frac{G_R \lambda^2}{(4\pi R_J)^2} \cdot \frac{L_J}{kT_s F_N} \tag{B.1}$$

where G_R = radar mainlobe antenna gain

R_J = range to jammer

L_J = antenna to receiver losses

k = Boltzmann's constant (1.38×10^{-23} Joule/°K)

T_s = effective system temperature

F_N = receiver noise figure

λ = RF wavelength

The term L_J is a lumped loss term, and should include antenna, waveguide, and amplifier losses. Any processing gain for the target signal (such as coherent integration) should also be included in L_J. Typically, L_J is much less than one. T_s is assumed to be 290°K.

Noise jamming is assumed to add directly to noise and clutter, giving a total signal-to-interference ratio of

$$\frac{S}{I} = \frac{S}{N + C + J} \tag{B.3}$$

Signal-to-jamming power is given by:

$$\frac{S}{J} = \frac{S}{N} \cdot \frac{N}{J} \tag{B.4}$$

where S/N is computed as described in Appendix A. The S/I ratio is used to compute the single-scan detection probability:

$$P_{DSS} = P_{FA}^{\frac{1}{1 + S/I}} \tag{B.5}$$

And to determine if tracking is possible:

$$\frac{S}{I} > ACRIT \tag{B.6}$$

where ACRIT is the threshold tracking level.

If the AI radar has the ability to track-on-jam, a second threshold (TTOJ) is used with the J/N ratio:

$$\frac{J}{N} > TTOJ \tag{B.7}$$

When this condition occurs, the radar is assumed to track in angles only, not in range. Note that it is possible for both inequalities of Eqs. B.6 and B.7 to be satisfied. When this occurs, normal radar tracking takes precedence over track-on-jam.

Track break and deceptive jammers must capture the receiver in order to be effective. This is modeled by setting a "jammer effectiveness ratio," T_{JEFF} . The AI radar is assumed to operate normally as long as:

$$\frac{J}{S} < T_{JEFF} \tag{B.8}$$

If the inequality in Eq. B.8 is not satisfied, a track break jammer will prevent acquisition until burnthrough. No track-on-jam capability is assumed for this type of jamming.

DECM is also considered to be effective when $J/S > T_{JEFF}$. In this case, bias error terms are added to the range, azimuth, and/or elevation angles to the target. These errors impact the missile launch calculations and the AI maneuver instructions, which will be discussed in the next two appendices.

APPENDIX C

LAUNCH REQUIREMENTS

The ENGAGE II model imposes many constraints on the times when missile launches are possible. The constraints vary according to the type of missile and which track mode (normal radar, track-on-jam, or adjunct tracking) is being employed.

During normal radar track, a predicted impact point is calculated using the average missile velocity and the current target position and velocity. If DECM is being modeled, an erroneous target position is used in the predictions.

Figure C.1 depicts the geometry used to calculate the impact point. X is the distance ahead of the target to the impact point, V_M is the average missile velocity, and R_{LOS} is the range from the AI to the target. We can write an expression for X based on the law of cosines:

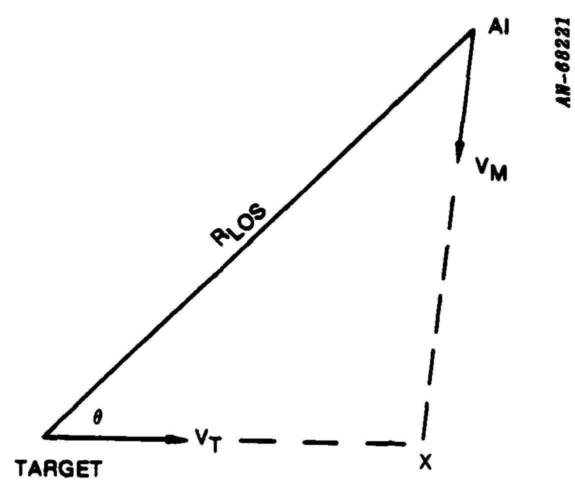

Figure C.1. Geometry for Impact Point Calculations

$$X = R_{LOS} \cdot \frac{\left[-\cos\theta \pm \sqrt{\cos^2\theta + (\rho^2 - 1)}\right]}{\rho^2 - 1} \tag{C.1}$$

where

$$\rho = \frac{V_M}{V_T}$$

The negative root is of no interest (it corresponds to negative flight time). In most cases, the missile velocity is not constant. For this reason, a two-step iteration is used to refine the estimate of average velocity. The first step uses the AI velocity to calculate an impact point (earliest collision point on target path which AI can reach). The range from the AI to this point is used to estimate the average missile speed. This speed is then used to find a second impact point, which is used to calculate the range to impact and the heading error (angle between the AI velocity vector and the line-of-sight vector to the impact point).

The following checks are made to determine if a missile launch is possible:

- The range to impact must be greater than the input minimum range and less than the maximum range.
- The heading error must be less than the input maximum.
- The velocity at impact must be greater than the target velocity.
- The current AI acceleration must be less than the input maximum g-limit.

Additional criteria are imposed depending on the type of missile:

- IR missiles must be within the aspect dependent lock-on range.

- Semi-active (LOBL) missiles must have seeker lock-on.
- No additional checks are made for active (LOAL) missiles, but they must achieve lock-on during flight before an input time limit prior to impact.

Seeker lock-on for all three types of missiles includes gimbal limit checks. RF missiles (both active and semi-active) require the signal-to-interference ratio (see Appendices A and B) to be greater than an input threshold.

Only RF missiles can be launched if the AI radar is tracking on noise jamming. In this mode, no impact predictions are made, since the radar is presumed to have no range or range rate data. Only three checks are made:

- The heading error (which in this case is the angle between the AI velocity vector and the jam strobe) is less than the allowed heading error.
- The current AI acceleration is less than the maximum allowed.
- The missile (either active or semi-active RF) has a home-on-jam capability and the J/N ratio exceeds an input threshold level.

Since no checks are made on range or velocity, it is quite possible for missiles to be launched which have no chance of reaching the target.

Missile launches using the passive track adjunct mode are very similar to normal radar track launches. Since the track adjunct is assumed to have no Doppler measurement, no prediction is used. Instead, the current target position is used to determine if the target is within missile reach. Semi-active missile launches are not allowed during adjunct tracking since they require radar illumination.

APPENDIX D
AI MANEUVERS

During the course of any air-to-air engagement, the interceptor may be required to perform several types of maneuvers. Since ENGAGE II does not include a reactive target, no "dog-fighting" is modeled. Thus, the list of required maneuvers can be limited to:

- Direct Pursuit--in which the AI flies directly toward the target. This maneuver is used during track-on-jam and adjunct tracking.
- Lead Pursuit—in which the AI flies toward a predicted impact point ahead of the target. This maneuver is used during normal radar track.
- Breakaway—in which the AI flies toward an offset position in order to convert to a stern attack.
- Tail Chase—in which the AI attempts to achieve a position to launch rear-hemisphere (IR) missiles or to fire guns.

All four types of maneuvers are in some way related to the target position. Prior to acquiring the target, no maneuvers are allowed. Maneuver instructions are generated in a two-step process:

- An aimpoint is calculated.
- Heading changes necessary to align the AI velocity vector with the aimpoint are calculated.

We'll first discuss how the aimpoints are calculated for the four maneuvers.

The aimpoint for direct pursuit is just the current target position.

The aimpoint for lead pursuit is determined as described in Appendix C for any remaining missiles. If no impact point can be found—as can happen if the missile velocity is too low—the aimpoint calculated using the AI velocity is used for maneuvers. The missile launch priority (an input) is used to select either the IR or RF aimpoint.

The aimpoint used for breakaway is offset from the target by a distance equal to the AI's turn diameter, and behind the target by the desired tail chase position. This maneuver is only used when:

- The AI is in front of the target, and
- No missiles with forward hemisphere capability are left

The breakaway continues until a position has been reached from which the AI can turn to the target's stern. This occurs when:

$$\Delta \cdot \frac{V_T}{T_R} = R \cdot \cos(\theta) + \frac{V_I}{T_R} \cdot \sin(\Delta) + R_T \qquad (D.1)$$

where
Δ = angle through which AI must turn
V_T = target velocity
T_R = AI turn rate (radians/sec)
R = range from AI to target
θ = aspect angle from target to AI
R_T = desired distance behind target
V_I = Interceptor Velocity

Figure D.1 shows some of the variables in Eq. D.1. The term $\Delta \cdot V_T/T_R$ is the distance the target will move while the AI is turning through the angle Δ. $R \cos(\theta)$ is the distance the AI is ahead of the target. $V_I/T_R \cdot \sin(\Delta)$ is the distance along the target's velocity vector the AI will move during the turn.

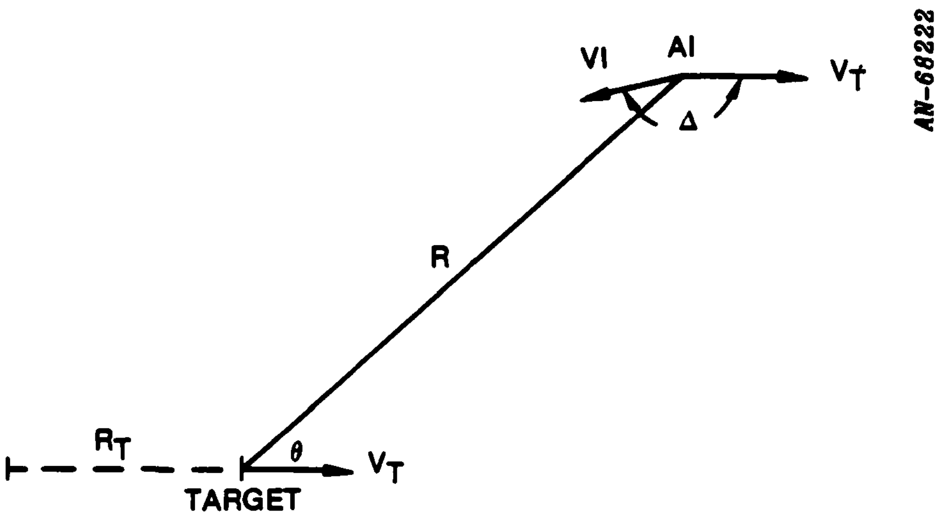

Figure D.1. Breakaway Geometry

The tail chase maneuver starts when all radar missiles are fired and the AI is behind the target, or when breakaway ends (left-hand side of Eq. D.1 less than right-hand side). The aimpoint for tail chase is behind the target by a distance:

$$D = \Delta \frac{V_T}{T_R} - R_T \tag{D.2}$$

Note that $D \rightarrow R_T$ as $\Delta \rightarrow 0$. When the range to the target becomes smaller than R_T , the AI would fly a circle (360° turn) if Eq. D.2 were strictly enforced. For this reason, R_T is modified to be the minimum of $R/2$ and R_T.

The AI velocity is also modified during breakaway and tail chase. During breakaway, the AI is allowed to accelerate up to an input maximum velocity. During tail chase, the AI velocity needs to be more tightly controlled to prevent flying past the target or falling too far behind. Since most aircraft cannot slow down as fast as they can accelerate, the deceleration limit is used as the key to speed control. The time to fly by is estimated by:

$$T_F \simeq \frac{\text{Range}}{V_I - V_T} \tag{D.3}$$

where V_I = AI velocity
V_T = target velocity

The time it would take the AI to slow down, assuming a smooth deceleration, and allowing a safety factor of 2, is:

$$T_s = \frac{2(V_I - V_T)}{D_L} \tag{D.4}$$

where D_L is the maximum deceleration.

The factor of 2 is used as a safety margin, since the simulation uses discrete time steps. The velocity change is given by:

$$V_\Delta = \begin{cases} \left(\text{MIN} - \dfrac{(V_I - V_T)\cdot T_I}{T_F},\ - D_L \cdot T_I\right) & \text{if} \quad T_F < T_s \\ + A_L \cdot T_I \dfrac{(T_F - T_s)}{T_s} & \text{if} \quad T_s \leq T_F \leq 2T_s \\ + A_L \cdot T_I & \text{if} \quad T_F > 2T_s \end{cases} \tag{D.5}$$

where V_Δ = incremental velocity
A_L = acceleration limit
T_I = current simulation time step

and the remaining variables have been previously defined.

Further checks are made to insure that the incremental velocity will not place the AI velocity outside the input range:

$$V_{MIN} \le V_I + V_\Delta \le V_{MAX} \tag{D.6}$$

Once the aimpoint and incremental velocity have been determined, a turn is commanded, based on the angle (ψ) between the current AI velocity vector and the line-of-sight vector to the aimpoint. The desired turn rate ($\dot{\psi}$) is:

$$\dot{\psi} = \psi / T_I \tag{D.7}$$

For large ψ, the desired turn rate can exceed the turn rate limit:

$$\dot{\psi}_L = \frac{G_M \cos(\gamma) + \sqrt{G_L^2 - \left(G_M \sin(\gamma)\right)^2}}{V_I} \tag{D.8}$$

where G_M = component of gravity in direction of AI velocity vector

γ = AI roll angle from vertical

G_L = g-load limit on AI (input)

V_I = AI velocity

The factor G_M accounts for dive angle:

$$G_M = -g \cos(EL) \tag{D.9}$$

where $g = 9.8\ m/s^2$

EL = AI dive angle

The commanded turn rate is then:

$$\dot{\psi}_c = \mathrm{MIN}(\dot{\psi}, \dot{\psi}_L) \qquad (D.10)$$

A further limitation is imposed if the AI would be required to roll at an excessive rate to achieve the new heading. The required roll rate is:

$$\dot{\gamma}_R = \frac{\gamma_N - \gamma_o}{T_I} \qquad (D.11)$$

where γ_N = the desired roll angle

γ_o = the last roll angle

T_I = incremental time step

If $\dot{\gamma}_R$ exceeds the input roll rate limit, the turn is delayed until the desired roll angle (γ_N) is achieved.

In cases where the current or desired turn directions are downward, special checks are made to assure that the AI does not fly into the ground. A pull-up maneuver is commanded whenever:

$$\left| \frac{H + V_Z \cdot T_I - 200}{.8 V_Z} \right| < \frac{|EL|}{\dot{\psi}_L} \qquad (D.12)$$

where H = the current AI altitude

V_Z = the vertical component of the AI velocity

T_I = the incremental time step

EL = the elevation angle of the AI

$\dot{\psi}_L$ = the maximum turn rate (Eq. D.8)

The left-hand side of Eq. D.12 is the approximate time to reach an altitude of 200 feet if a pull-up were started. The factor of .8

accounts for the reduction in vertical velocity as the pull-up is incremented. The term $EL/\dot{\psi}_L$ is the approximate time it would take to change the elevation angle from EL to zero.

Before each new maneuver is implemented, another check is made to make sure the new maneuver will allow the AI time to pull up later. This check uses the same form as Eq. D.12 with V_Z replaced with the estimate of the vertical velocity after the new maneuver and EL with an estimate of the new dive angle.

Once the maneuver direction, turn rate, and speed acceleration have been determined, the AI trajectory is updated using the same equations of motion as for target maneuvers as described in Appendix G.

APPENDIX E

MISSILE GUIDANCE ALGORITHMS

The ENGAGE II missile guidance model contains three options for guiding the missile toward its target. They are selected by the input guidance parameter KGYDE. For KGYDE=0, pursuit guidance is used. For KGYDE=1, proportional guidance is used. For KGYDE=2, a special tail-chase proportional guidance is used. [Note: each input guidance parameter has a separate value for radar and IR missiles. For example, you might input KGYDE(RADMIS)=1 and KGYDE(IRMIS)=2.]

E.1 PURSUIT GUIDANCE

First, the relative position and velocity vectors are computed.

$$\underline{r}_r = \underline{r}_T - \underline{r} \tag{E.1}$$

$$\underline{V}_r = \underline{V}_T - \underline{V} \tag{E.2}$$

where $\underline{r}_T$ and $\underline{r}$ are the position vectors of the target[1] and missile, and $\underline{V}_T$ and $\underline{V}$ are their velocity vectors. The estimated time-to-go to closest approach is then

$$t_g = -(\underline{r}_r \cdot \underline{V}_r)/(\underline{V}_r \cdot \underline{V}_r) \tag{E.3}$$

Next, compute

$$\underline{U} = (\underline{r}_r/|\underline{r}_r|) \times \underline{V} \tag{E.4}$$

[1]The target state used is the true state at a lag time (DELTAC) before the current time. This state is extrapolated, using constant velocity, to the current time.

and the pursuer's "lateral" velocity

$$V_L = |U| \tag{E.5}$$

The unit lift vector direction is then

$$\underline{1}_L = (\underline{V} \times \underline{U})/|\underline{V} \times \underline{U}| \tag{E.6}$$

and the desired lift acceleration magnitude is computed as

$$a_{Ld} = G_1 V_L/\max(t_g, 1) \tag{E.7}$$

where G_1 is an input guidance gain, GNAV1.

E.2 PROPORTIONAL GUIDANCE

As in pursuit guidance, the relative position and velocity vectors are computed as in Eqs. E.1 and E.2. The line-of-sight angular rate is then

$$\underline{W} = (\underline{r}_r \times \underline{V}_r)/(\underline{r}_r \cdot \underline{r}_r) \tag{E.8}$$

and the unit lift vector is

$$\underline{1}_L = (\underline{W} \times \underline{V})/|\underline{W} \times \underline{V}| \tag{E.9}$$

and the desired lift acceleration magnitude is

$$a_{Ld} = G_1 |\underline{W} \times \underline{V}| \tag{E.10}$$

E.3 TAIL-CHASE PROPORTIONAL GUIDANCE

Again, relative position and velocity vectors are computed as in Eqs. E.1 and E.2 and the line-of-sight rate as in Eq. E.8. Next, a phantom "tail-chase" point is computed as

$$\underline{r}_p = \underline{r}_T - S\underline{V}_T/|\underline{V}_T| \tag{E.11}$$

where S , the phantom target offset, is defined as

$$S = \max[\min(|\underline{r}_r|, r_{max}), r_{min}] \tag{E.12}$$

and r_{max} and r_{min} are input guidance parameters RMAX and RMIN.

Next the angles

$$\theta_o = \cos^{-1}(\underline{r}_r \cdot \underline{V}_T)/|\underline{r}_r||\underline{V}_T| \tag{E.13}$$

$$\phi = \cos^{-1}(\underline{V} \cdot \underline{V}_T)/|\underline{V}||\underline{V}_T| \tag{E.14}$$

are computed, and

$$T = \tan(A) - |\underline{V}_T|/[|\underline{V}| \cos(A)] \tag{E.15}$$

where A is the input guidance parameter ATANG. Finally, the computed guidance gain is

$$G_C = (A - \phi)/[\tan^{-1}(T) - \theta_o] \qquad \text{E.16)}$$

The actual gain used is

$$G = \max[\min(G_C, G_2), G_1] \tag{E.17}$$

where G_1 and G_2 are the input guidance parameters GNAV1 and GNAV2. The unit lift vector is given by Eq. E.9 and the desired lift acceleration magnitude is

$$a_{Ld} = G|\underline{W} \times \underline{V}| \tag{E.18}$$

APPENDIX F
MISSILE EQUATIONS OF MOTION

The point-mass model employed in ENGAGE II for the missile's flight dynamics includes aerodynamic, gravitational, and rocket thrust forces, a time-varying mass, and provision for up to seven stages. The model requires the following input parameters for each stage to physically describe the missile:

- Initial vacuum thrust T_o (CPTHRST)
- Initial weight W_o (CPMASSI)
- Final weight W_f (CPMASSF)
- Burn time t_b (CPTB)
- Nozzle exit area A_e (CPNEA)
- Aerodynamic reference area A (CPAREA)
- Either

    Cone angle θ_c (CPCONE) and induced axial force coefficient C_{x_2} (CX2CP), to compute the axial force coefficient C_x by functional expression

- Or, alternatively,

    A table for powered flight (CXCPKB)[1] and, if applicable, for coasting flight (CXCPKC),[1] or C_x as a function of Mach number M and angle of attack α

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[1]The letter K in these tables represents the digit 1, 2, ..., 7 corresponding to the stage number.

- Either

  Normal force coefficients C_{N_1} (CN1CP) and C_{N_2} (CN2CP) to compute the normal force C_N as a quadratic expression in α

- Or, alternatively,

  A table (CNCPK)[1] of C_N as a function of M and α

- Coast time before ignition (TCOB4I) and after burnout (TCOABO)

- Maximum permissible normal acceleration loading a_{Nmax} (ANMAXCP)

- Maximum angle-of-attack α_{max} (ALFMXCP)

Each of the foregoing input parameters will have separate tables for each missile type (RADMIS or IRMIS).

Figure F.1 shows the aerodynamic and thrust acceleration vectors used in the model.

The missile's equations of motion are

$$\dot{\underline{r}} = \underline{v} \tag{F.1}$$

$$\dot{\underline{v}} = \underline{a} = a_v \underline{1}_v + a_L \underline{1}_L + \underline{g} \tag{F.2}$$

In these equations, $\underline{r}$, $\underline{v}$, and $\underline{a}$ are the missile's position, velocity and acceleration vectors, respectively; $\underline{1}_v$ and $\underline{1}_L$ are unit vectors

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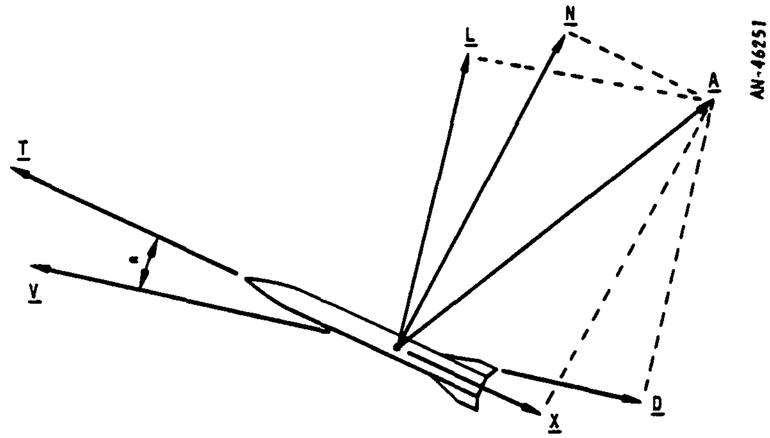
[1]The letter K in these tables represents the digit 1, 2, ..., 7 corresponding to the stage number.



V = VELOCITY
T = THRUST VECTOR
L = LIFT ACCELERATION VECTOR $= a_L 1_L$
N = NORMAL ACCELERATION VECTOR
A = TOTAL AERODYNAMIC ACCELERATION VECTOR
D = DRAG ACCELERATION VECTOR $= - a_v 1_v$
X = AXIAL ACCELERATION VECTOR
α = ANGLE OF ATTACK

Figure F.1. Definition of Aerodynamic and Thrust Acceleration Vectors

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in the velocity and lift direction, and a_v and a_L are the corresponding components of thrust and aerodynamic acceleration in these directions; g is the gravitational acceleration. The gravity term is assumed to be constant (earth-surface value). The acceleration terms a_v and a_L are given by

$$a_v = \frac{1}{m} [(T - C_x QA) \cos \alpha - C_N QA \sin \alpha] \tag{F.3}$$

$$a_L = \frac{1}{m} [(T - C_x QA) \sin \alpha + C_N QA \cos \alpha] \tag{F.4}$$

where T is the delivered thrust; C_x and C_N are the axial and normal aerodynamic force coefficients; Q, the dynamic pressure, is given by

$$Q = \frac{\rho \underline{v} \cdot \underline{v}}{2} \tag{F.5}$$

where ρ is the atmospheric density, computed as a piecewise exponential function of the missile's altitude; and m is the current mass of the missile.

Two alternative models for the thrust profile are available in the program. The first assumes constant vacuum thrust for the duration of the stage burn time:

$$T_{vac} = T_o \tag{F.6}$$

The second model (selected by input of the initial thrust CPTHRST as a negative value) assumes a decreasing vacuum thrust shaped to yield constant axial acceleration:

$$T_{vac} = T_o \left(\frac{W_f}{W_o}\right)^{(t-t_I)/t_b} \tag{F.7}$$

where t_I is the ignition time of the current stage. The delivered thrust is then obtained from the vacuum thrust by the expression

$$T = T_{vac} - pA_e \tag{F.8}$$

where p is the atmospheric pressure corresponding to the missile's altitude, computed as

$$p = \frac{\rho g c^2}{\gamma} \tag{F.9}$$

where c is the local velocity of sound, a piecewise linear function of the missile's altitude, g is the gravitational constant, and γ the gas ratio of specific heats (1.401). During coasting periods, of course, $T = 0$.

The missile's mass m is computed according to one of two formulas, depending on which form of thrust calculation is being employed. For the constant thrust model, mass decreases linearly with time:

$$m = \frac{1}{g}\left[W_o - (W_o - W_f)\left(\frac{t - t_I}{t_b}\right)\right] \tag{F.10}$$

For the variable thrust model,

$$m = \frac{W_o}{g}\left(\frac{W_f}{W_o}\right)^{(t-t_I)/t_b} \tag{F.11}$$

During coasting, m remains constant at W_o/g or W_f/g for pre-ignition or post-burnout coasts, respectively.

The aerodynamic coefficients C_x and C_N are generally expressed as functions of M and α, where the Mach number M is obtained from the missile's velocity by the relation

$$M = \frac{|\underline{v}|}{c} \tag{F.12}$$

Either or both of these functions may be input to the prog· ɑ in tabular form. If not so input, functional expressions will be employed. The expression for C_x represents a simplified theoretical model for the axial force coefficient of a cone:

$$C_x = \begin{cases} 2\sin^2\theta_c + C_{x_2}\alpha^2 & ; \quad M \le 0.5 \\ 2\sin^2\theta_c\left[1. + \left(\dfrac{0.3125 + 1.118\sin\theta_c}{0.0625 + 1.118\sin\theta_c} - 1. + \dfrac{0.4444k}{2\sin^2\theta_c}\right)\left(M - 0.5\right)\right] & \\ \qquad + C_{x_2}\alpha^2 & ; \quad 0.5 \le M \le 1.5 \\ 2\sin^2\theta_c\left(\dfrac{0.3125 + \sqrt{M^2 - 1}\,\sin\theta_c}{0.0625 + \sqrt{M^2 - 1}\,\sin\theta_c}\right) + \dfrac{k}{M^2} + C_{x_2}\alpha^2 & ; \quad M > 1.5 \end{cases} \tag{F.13}$$

where $k = 0$ during powered flight, and $k = 1$ during coasting flight. The expression for C_N is a quadratic in α :

$$C_N = C_{N_1}\alpha + C_{N_2}\alpha^2 \tag{F.14}$$

The angle of attack α is taken to be the smallest of the following three quantities: (1) commanded angle-of-attack, α_c ; (2) limiting angle of attack, α_{max} ; and (3) angle-of-attack, α_{Nmax} , yielding limiting normal acceleration, a_{Nmax} ; as computed by iteratively solving the implicit equation

$$a_{Nmax} = \frac{C_N(M, \alpha_{Nmax})QA}{m} \tag{F.15}$$

for α_{Nmax}.

The commanded angle-of-attack is obtained by iteratively solving the equation

$$a_{LA} = \frac{QA}{m} [C_N(M,\alpha_c) \cos \alpha_c - C_x(M,\alpha_c) \sin \alpha_c] \tag{F.16}$$

for α_c . Here, a_{LA} is the desired <u>aerodynamic</u> lift acceleration. It is computed from the desired <u>total</u> lift acceleration a_{Ld} by

$$a_{LA} = a_{Ld} - I_g \underline{g} \cdot \underline{1}_L \tag{F.17}$$

where a_{Ld} is computed by the guidance algorithm and I_g is zero if the input guidance parameter INCLG is zero or negative, and I_g is one otherwise.

The unit lift vector, $\underline{1}_L$, is computed by the guidance algorithm.

Equations F.1 and F.2 are numerically integrated using fourth-order Runge-Kutta integration with a time-step specified by the input parameter DTINT. Integration is terminated at each dynamic discontinuity (such as staging, burnout, or target-closest-approach) and, if appropriate, restarted after the discontinuity.

The missile trajectory is integrated in conjunction with the target trajectory. A stack of up to ten missile state vectors is maintained and updated in time whenever the model requires a new state outside the time-span of the current stack. For each state vector, i , in the stack, the quantities

t_i (time)

$\underline{r}(t_i)$ (position)

$\underline{v}(t_i)$ (velocity)

$\underline{a}(t_i)$ (acceleration)

$$\underline{f}(t_i) = (10\underline{\sigma}_i - 4\Delta_i\underline{\mu}_i + 0.5\Delta_i^2\underline{\nu}_i)/\Delta_i^3 \qquad \text{(F.18)}$$

$$\underline{g}(t_i) = (-15\underline{\sigma}_i + 7\Delta_i\underline{\mu}_i - \Delta_i^2\underline{\nu}_i)/\Delta_i^4$$

$$\underline{h}(t_i) = (6\underline{\sigma}_i - 3\Delta_i\underline{\mu}_i + 0.5\Delta_i^2\underline{\nu}_i)/\Delta_i^5$$

are computed and saved. Here

$$\underline{\sigma}_i = \underline{r}_{i+1} - \underline{r}_i - \Delta_i\underline{v}_i - 0.5\Delta_i^2\underline{a}_i$$

$$\underline{\mu}_i = \underline{v}_{i+1} - \underline{v}_i - \Delta_i\underline{a}_i \qquad \text{(F.19)}$$

$$\underline{\nu}_i = \underline{a}_{i+1} - \underline{a}_i$$

$$\Delta_i = t_{i+1} - t_i$$

During program computations, whenever a missile state is required at an arbitrary time, t, the stack is checked. If t is not within the stack's time-span, another step (nominally 1 second) is taken and the stack updated. This process is repeated as necessary until the time t is within the stack's time-span. The state vector at t is then computed as follows. First, a time, t_i, in the stack is located such that $t_i \le t < t_{i+1}$. Then, using the stored quantities from Eq. F.18,

$$\begin{aligned}
\underline{r}(t) &= \underline{r}(t_i) + \underline{v}(t_i)(t - t_i) + 0.5\underline{a}(t_i)(t - t_i)^2 \\
&\quad + \underline{f}(t_i)(t - t_i)^3 + \underline{g}(t_i)(t - t_i)^4 + \underline{h}(t_i)(t - t_i)^5 \\
\underline{v}(t) &= \underline{v}(t_i) + \underline{a}(t_i)(t - t_i) + 3\underline{f}(t_i)(t - t_i)^2 \\
&\quad + 4\underline{g}(t_i)(t - t_i)^3 + 5\underline{h}(t_i)(t - t_i)^4 \\
\underline{a}(t) &= \underline{a}(t_i) + 6\underline{f}(t_i)(t - t_i) + 12\underline{g}(t_i)(t - t_i)^2 \\
&\quad + 20\underline{h}(t_i)(t - t_i)^3
\end{aligned} \tag{F.20}$$

The vector functions $\underline{f}(t_i)$, $\underline{g}(t_i)$, and $\underline{h}(t_i)$ are calculated as in Eq. F.18 so as to satisfy the Taylor's series expansions in $(t - t_i)$ for $\underline{r}$, $\underline{v}$, and t over the range $t_i \le t < t_{i+1}$.

If, for some reason, a request is made for a missile state at a time less than the earliest stack time, ENGAGE II will issue a diagnostic complaint and abort. The program has been configured for easy expansion of the stack size if other changes in program logic should require it.

The state-vector stack, as mentioned, is maintained at a nominal 1-second time step (independent of the integration step size DTINT). However, when a discontinuity such as staging, burnout, etc., occurs, integration is interrupted. In such cases, the stack will hold two state vectors having the same time. These state vectors will be identical except for the accelerations (and $\underline{f}$, $\underline{g}$, and $\underline{h}$ terms of Eq. F.18). They represent the states immediately prior to, and just after, the discontinuity. The first of these two states is never used in the interpolation scheme of Eq. F.20 since an arbitrary time will not fall between its time and the second state's time.

APPENDIX G

TARGET MOTION MODEL

The target aircraft trajectory is described by its initial conditions (position and velocity), a maneuver schedule start time, and an input schedule of maneuver segments. The initial conditions and maneuver schedule start-time are generated internally by, or input to, the program. The maneuver schedule for the target is an input array of parameters for up to 30 segments. For each segment, these parameters are:

- Duration of segment
- Maneuver roll direction, ϕ
- Maneuver magnitude (velocity vector turn rate), ω_V
- Speed acceleration, a_V
- Bank angle[1]

If, during program execution, the total time duration of all segments is exhausted, the maneuver schedule will repeat from the beginning.

Maneuver direction is defined as follows: A plane, which we'll call the "lift plane", is perpendicular to the instantaneous velocity vector. The unit lift vector, $\underline{1}_L$, will lie in this plane, and will be in the direction shown in Fig. G.1, given the roll direction ϕ .

The lift magnitude, a_L , is computed as

$$a_L = \omega_V |\underline{v}_T| \tag{G.1}$$

[1] The bank angle is not used in the present program. It was included for possible future use in target geometrical computations.

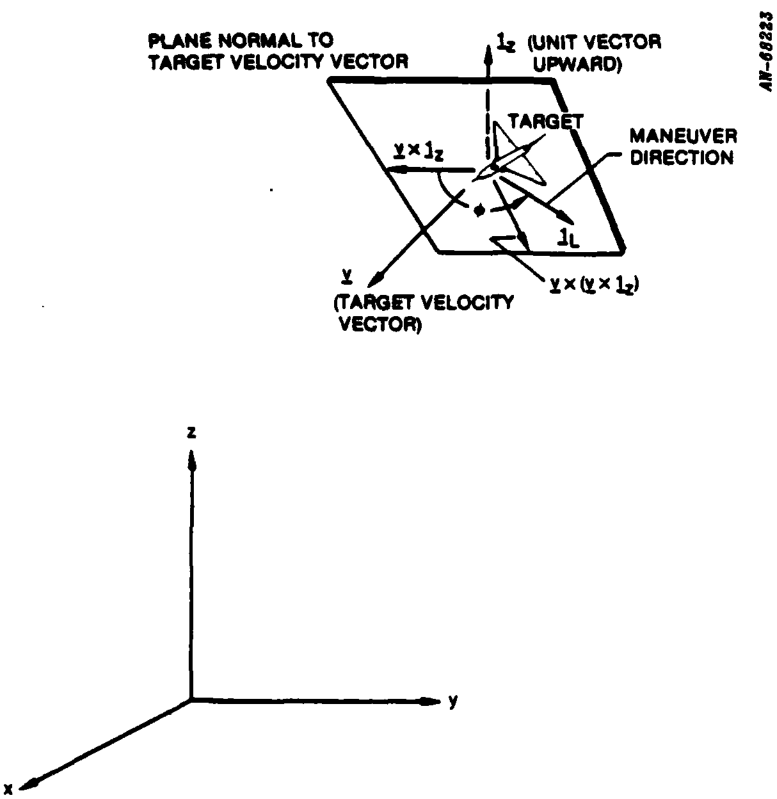

Figure G.1. Coordinate System for Specifying Maneuver Direction

---

where ω_v is the input velocity-vector turn rate and $\underline{v}_T$ is the instantaneous target velocity vector.

The target equations of motion are

$$\dot{\underline{r}}_T = \underline{v}_T \tag{G.2}$$

$$\dot{\underline{v}}_T = \underline{a}_T = a_v \underline{1}_v + a_L \underline{1}_L \tag{G.3}$$

where $\underline{r}_T$, $\underline{v}_T$, and $\underline{a}_T$ are the target's position, velocity, and acceleration vectors, and $\underline{1}_v$ and $\underline{1}_L$ are unit vectors in the velocity and lift directions.

During maneuver segments where ω_v is non-zero, Eqs. G.2 and G.3 are numerically integrated using fourth-order Runge-Kutta integration with a 1-second time-step. Integration is terminated at the end of each maneuver segment and restarted with the next segment. For segments which have $\omega_v = 0$ (no turning), the numerical integration is bypassed since the closed-form solutions

$$\underline{r}(t_{i+1}) = \underline{r}(t_i) + \underline{v}(t_i)\Delta_i + 0.5\underline{a}(t_i)\Delta_i^2$$

$$\underline{v}(t_{i+1}) = \underline{v}(t_i) + \underline{a}(t_i)\Delta_i \tag{G.4}$$

$$\underline{a}(t_{i+1}) = \underline{a}(t_i)$$

where

$$\Delta_i = t_{i+1} - t_i \tag{G.5}$$

can be used when the acceleration (if any) is only along the velocity vector.

The target trajectory is maintained in a stack of up to twenty state vectors. Whenever the model requires a target state, the current stack is used unless the time is outside the time-span of the stack. If outside the time-span, the stack is updated by integration of the trajectory (or re-initialized and re-integrated if, for some reason, the time is earlier than any in the stack). The quantities saved for each state vector in the stack are the time, position, velocity, acceleration, and higher-order terms. These are the same as for the missile state-vector stack described in Appendix F. The state vector for an arbitrary time within the stack's time-span is computed by an interpolation scheme which is also described in Appendix F.

APPENDIX H

MISSILE FLIGHT TABLE GENERATION

An ENGAGE II utility program, AATEST, is provided with ENGAGE II to help the user generate the input missile flight tables for a specific scenario. Program AATEST uses the same three-degree-of-freedom flight model as ENGAGE II, and requires the same missile input data (in the same format) for guidance, propulsion, aerodynamics, and integration of missile flight trajectories. (However, ENGAGE II inputs other than missile data are not permitted by AATEST.) It interactively asks the user for the scenario inputs desired. The missile is assumed to be launched at the same altitude as the target, and in direct tail pursuit. Missile launch occurs at the center of the local coordinate system. Both the target and the missile travel along the positive X-axis. The program outputs the missile state vector (time, position, velocity, and acceleration), angle-of-attack, and range (to the target) at each time step requested for the total requested display time. Velocity and range can be directly extracted from the output of AATEST to use as input for the ENGAGE II AAM flight table, described below in Sec. 3.3.1. Program use is briefly described below, and a sample output is provided as Fig. H.1.

- **AATEST Run Description**

AATEST allows the user to copy all file and terminal interactions to the output file.

DO YOU WANT HARDCOPY OUTPUT (Y/N)

After the user types in "Y" or "N", the program reads the missile input data, described in Secs. 3.3.4 and 3.3.5., from unit 3. Note that other

```
***UNIT   3 INPUT - /   AATEST SAMPLE PROBLEM
***UNIT   3 INPUT - / This is aero-data for a medium missile with 8s burn and 19s sustain
***UNIT   3 INPUT - KOYDE(RADMIS)=1
***UNIT   3 INPUT - GNAVI(RADMIS)=6
***UNIT   3 INPUT - INCLG(RADMIS)=1
***UNIT   3 INPUT - CPMASSI(RADMIS)= 244.9KG,196.9KG
***UNIT   3 INPUT - DTINT(RADMIS)=.2,.2
***UNIT   3 INPUT - CPTHRST(RADMIS)=14950NEWT,4260NEWT
***UNIT   3 INPUT - CPMASSF(RADMIS)=196.9KG,163.1KG
***UNIT   3 INPUT - TCOABD(RADMIS)=0.99999
***UNIT   3 INPUT - CPNEA(RADMIS)= 209.4SQCM, 209.4SQCM
***UNIT   3 INPUT - CPTB(RADMIS)= 8.SEC, 18.9SEC
***UNIT   3 INPUT - CPAREA(RADMIS)= 394.SQCM, 394.SQCM
***UNIT   3 INPUT - ALFMXCP(RADMIS)= 6.DEG,6.DEG
***UNIT   3 INPUT - ANMAXCP(RADMIS)= 340, 340
***UNIT   3 INPUT - CXCP1B (RADMIS) (DEG)
***UNIT   3 INPUT - 1.25,   0,.8,1.25,.8,2.7,1.,5.7,1.6,END
***UNIT   3 INPUT - 1.75,    0,.8,1.2,.8,2.4,1.,4.8,1.6,END
***UNIT   3 INPUT - 2.00,    0,.7,1.1,.7,2.3,.9,4.6,1.4,END
***UNIT   3 INPUT - 3.00,   0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
***UNIT   3 INPUT - 4.00,   0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
***UNIT   3 INPUT - 5.00,   0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
***UNIT   3 INPUT - CXCP1C  (RADMIS) (DEG)
***UNIT   3 INPUT - 1.25,   0,.8,1.25,.8,2.7,1.,5.7,1.6,END
***UNIT   3 INPUT - 1.75,    0,.8,1.2,.8,2.4,1.,4.8,1.6,END
***UNIT   3 INPUT - 2.00,    0,.7,1.1,.7,2.3,.9,4.6,1.4,END
***UNIT   3 INPUT - 3.00,   0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
***UNIT   3 INPUT - 4.00,   0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
***UNIT   3 INPUT - 5.00,   0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
***UNIT   3 INPUT - CNCP1  (RADMIS) (DEG)
***UNIT   3 INPUT - 1.25,    0,0, 1.25,2.4, 2.75,5, 5.7,10, END
***UNIT   3 INPUT - 1.75, 0,0, 1.2,2.3, 2.4,4.8, 4.8,10., END
***UNIT   3 INPUT - 2.00, 0,0, 1.1,1.2, 2.3,4, 4.6,8.5, END
***UNIT   3 INPUT - 3.00, 0,0, 1.2,1.4, 2.5,2.6, 5,5, END
***UNIT   3 INPUT - 4.00, 0,0, 1.3,1.25, 2.6,2.25, 5.3,4.5, END
***UNIT   3 INPUT - 5.00, 0,0, 1.3,1.1, 2.8,2, 5.7,3.9, END, END
***UNIT   3 INPUT - CXCP2B  (RADMIS) (DEG)
***UNIT   3 INPUT - 1.25,   0,.8,1.25,.8,2.7,1.,5.7,1.6,END
***UNIT   3 INPUT - 1.75,    0,.8,1.2,.8,2.4,1.,4.8,1.6,END
***UNIT   3 INPUT - 2.00,    0,.7,1.1,.7,2.3,.9,4.6,1.4,END
***UNIT   3 INPUT - 3.00,   0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
***UNIT   3 INPUT - 4.00,   0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
***UNIT   3 INPUT - 5.00,   0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
***UNIT   3 INPUT - CXCP2C  (RADMIS) (DEG)
***UNIT   3 INPUT - 1.25,   0,.8,1.25,.8,2.7,1.,5.7,1.6,END
***UNIT   3 INPUT - 1.75,    0,.8,1.2,.8,2.4,1.,4.8,1.6,END
***UNIT   3 INPUT - 2.00,    0,.7,1.1,.7,2.3,.9,4.6,1.4,END
***UNIT   3 INPUT - 3.00,   0,.6, 1.2,.6, 2.5,.75, 5.,1.1, END
***UNIT   3 INPUT - 4.00,   0,.6, 1.3, .6, 2.6,.7, 5.3,.9, END
***UNIT   3 INPUT - 5.00,   0,.5, 1.3,.5, 2.8,.6, 5.7,.8, END,END
***UNIT   3 INPUT - CNCP2  (RADMIS) (DEG)
***UNIT   3 INPUT - 1.25,    0,0, 1.25,2.4, 2.75,5, 5.7,10, END
***UNIT   3 INPUT - 1.75, 0,0, 1.2,2.3, 2.4,4.8, 4.8,10., END
***UNIT   3 INPUT - 2.00, 0,0, 1.1,1.2, 2.3,4, 4.6,8.5, END
***UNIT   3 INPUT - 3.00, 0,0, 1.2,1.4, 2.5,2.6, 5,5, END
***UNIT   3 INPUT - 4.00, 0,0, 1.3,1.25, 2.6,2.25, 5.3,4.5, END
***UNIT   3 INPUT - 5.00, 0,0, 1.3,1.1, 2.8,2, 5.7,3.9, END, END
***UNIT   3 INPUT - END
```

Figure H.1. AATEST Sample Output

```
INPUT ANY NEW PARAMETERS, TERMINATING WITH 'END'  (OR 'STOP' TO QUIT)
?
end
INPUT ALTITUDE (FT)
?
10000
INPUT INITIAL MISSILE SPEED, TARG. SPEED (FPS)
?
800,400
INPUT INITIAL RANGE TO TARGET (FT)
?
60000
INPUT TIME STEP, TOTAL TIME (SEC)
?
4,60
MISSILE TRAJECTORY...
```

T,SEC	X,FT	Y,FT	Z,FT	VX,FPS	VY,FPS	VZ,FPS	AX,FPSS	AY,FPSS	AZ,FPSS	ALFA,DEG	RNG,FT
0.0000	0.0	0.0	10000.0	800.0	0.0	0.0	169.3	0.0	0.2	1.1	60000.0
4.0000	4540.0	0.0	9999.2	1463.4	0.0	-0.5	159.5	0.0	0.0	0.3	57060.0
8.0000	11611.9	0.0	9997.3	2059.0	0.0	-0.7	-36.5	0.0	-0.1	0.3	51588.1
12.0000	19566.3	0.0	9993.7	1921.0	0.0	-1.2	-32.4	0.0	0.1	0.2	45233.7
16.0000	27006.9	0.0	9990.7	1804.4	0.0	-0.4	-25.2	0.0	0.2	0.2	39393.1
20.0000	34040.9	0.0	9990.3	1716.9	0.0	0.1	-18.8	0.0	0.1	0.2	33959.1
24.0000	40771.7	0.0	9989.1	1651.6	0.0	-0.8	-14.1	0.0	0.1	0.2	28828.3
28.0000	47242.6	0.0	9988.3	1543.3	0.0	0.6	-62.2	0.0	0.0	0.2	23957.4
32.0000	52966.1	0.0	9990.2	1329.1	0.0	0.3	-46.1	0.0	-0.1	0.3	19833.9
36.0000	57944.5	0.0	9990.8	1167.1	0.0	-0.1	-35.6	0.0	-0.1	0.4	16455.5
40.0000	62349.3	0.0	9989.5	1040.1	0.0	-0.6	-28.3	0.0	-0.1	0.4	13650.7
44.0000	66298.4	0.0	9986.8	937.9	0.0	-0.1	-23.2	0.0	0.5	0.6	11301.6
48.0000	69875.7	0.0	9988.8	853.3	0.0	0.9	-19.3	0.0	0.1	0.7	9324.4
52.0000	73142.8	0.0	9993.0	782.2	0.0	1.2	-16.4	0.0	0.1	0.8	7657.2
56.0000	76146.7	0.0	9998.0	721.3	0.0	1.1	-14.1	0.0	-0.1	0.9	6253.3
60.0000	78923.9	0.0	10001.4	668.5	0.0	0.6	-12.4	0.0	-0.1	1.1	5076.1
64.0000	81503.2	0.0	10001.3	622.1	0.0	-0.7	-11.0	0.0	-0.1	1.3	4096.8

Figure H.1. (Cont.)

TARGET TRAJECTORY...

T, SEC	X, FT	Y, FT	Z, FT	VX, FPS	VY, FPS	VZ, FPS
0.0000	60000.0	0.0	10000.0	400.0	0.0	0.0
4.0000	61600.0	0.0	10000.0	400.0	0.0	0.0
8.0000	63200.0	0.0	10000.0	400.0	0.0	0.0
12.0000	64800.0	0.0	10000.0	400.0	0.0	0.0
16.0000	66400.0	0.0	10000.0	400.0	0.0	0.0
20.0000	68000.0	0.0	10000.0	400.0	0.0	0.0
24.0000	69600.0	0.0	10000.0	400.0	0.0	0.0
28.0000	71200.0	0.0	10000.0	400.0	0.0	0.0
32.0000	72800.0	0.0	10000.0	400.0	0.0	0.0
36.0000	74400.0	0.0	10000.0	400.0	0.0	0.0
40.0000	76000.0	0.0	10000.0	400.0	0.0	0.0
44.0000	77600.0	0.0	10000.0	400.0	0.0	0.0
48.0000	79200.0	0.0	10000.0	400.0	0.0	0.0
52.0000	80800.0	0.0	10000.0	400.0	0.0	0.0
56.0000	82400.0	0.0	10000.0	400.0	0.0	0.0
60.0000	84000.0	0.0	10000.0	400.0	0.0	0.0
64.0000	85600.0	0.0	10000.0	400.0	0.0	0.0

INPUT ANY NEW PARAMETERS, TERMINATING WITH 'END' (OR 'STOP' TO QUIT)
?
stop

Figure H.1. (Cont.)

ENGAGE II input data is not allowed. The user is given an opportunity to add or change any missile data during the run.

INPUT ANY NEW PARAMETERS, TERMINATING WITH "END"
(OR "STOP" TO QUIT)

When the user has no more modifications for the missile data, he types in "END", and then he is prompted for the missile launch parameters.

INPUT ALTITUDE (FT)

The input altitude is the same for both the missile at launch and the target.

INPUT INITIAL MISSILE SPEED, TARG. SPEED (FPS)

The user inputs two velocities, the first the velocity of the missile at launch, which is the AI velocity, and the second the constant target velocity.

INPUT INITIAL RANGE TO TARGET (FT)

If a complete flyout table is desired, this range should be large enough to keep the target ahead of the missile until the total display times is expired.

INPUT TIME STEP, TOTAL TIME (SEC)

Total time is the total display time, usually the maximum guided flight time of the missile. Output is generated for this period of flight time. The time step should be chosen to provide a reasonable number of entries for the AAM flight table, which allows a maximum number of 25 entries.

The output follows, written to the terminal and to the hard copy file, if so requested. It includes the missile state vector (time, position vector, velocity vector, and acceleration vector), angle-of-attack, and range to the target at each time step for the total display time. This is followed by the target position and velocity vectors at each of the same time steps.

The user then may run another case.

```
INPUT ANY NEW PARAMETERS, TERMINATING WITH "END"
(OR "STOP" TO QUIT)
```

The user types in "STOP" when all cases are complete.

END

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